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# THE EXAMINATION OF WATERS AND WATER SUPPLIES

BY THE SAME AUTHOR.

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A SIMPLE METHOD OF WATER ANALYSIS.
SEVENTH EDITION

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PRESERVATIVES IN FOOD AND FOOD EXAMINATION. By J. C. Thresh and A. E. Porter.

# THE EXAMINATION

OF

# WATERS AND WATER SUPPLIES

BY

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ASSOCIATION OF WATERWORKS ENGINEERS

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# PREFACE

## TO SECOND EDITION

In this edition various sections have been amplified, one or two almost entirely re-written, and two additional ones added. Extended experience has enabled me to write with increased confidence of the modes of procedure and methods of analysis recommended, and, whilst the opinions of others may be freely quoted, everything recommended is based upon personal experience. The edition has had to be revised at a time when my leisure was very limited, and considerable intervals have, on occasions, elapsed between the revision of one section and another, and it is possible that a little repetition may have resulted. If such is found to be the case, it will probably be in connection with some point which I have thought it desirable especially to emphasise, and may therefore need no excuse.

Many persons who have found the book useful have kindly sent me suggestions. These have all been carefully considered; but the majority are not referred to, as they were either not germane to the subject or did not appear to be of any practical use. My one endeavour has been to make the work as practical and useful as possible.

The extended Table of, what may be called, complete analyses will, it is hoped, lead others to record similar results and thus increase our knowledge of underground water and of the causes

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of its variation. As great interest was taken in the plates representing deposits found in water, Mr. PRATCHETT has kindly prepared a few more for me, derived from waters with an interesting history. I have also to thank my friend Dr. Houston for giving me his views on Bacteriological Standards, expressed at length in Chapter X.

PUBLIC HEALTH LABORATORIES,
LONDON HOSPITAL MEDICAL COLLEGE, LONDON, E.

# PREFACE

## TO FIRST EDITION

The subjects discussed in this work have received a great deal of attention from me for many years, and it is possible that the results of my observations and experience may be of value to others interested in the important question of the protection of our water supplies from the risks of pollution.

When practising as a water analyst, before becoming a Medical Officer of Health, I strongly suspected that in deciding upon the character of a water supply we were laying far too much stress upon the results of chemical analyses of samples of water and far too little upon the examination of the sources from which they were derived. When, afterwards, my duties as Medical Officer afforded me the necessary opportunities for examining sources of supply, analysing the samples of water from such sources, and studying the effect of the water upon health, I was speedily convinced that the examination of the source of supply often afforded far more important information than could be obtained from the analytical results. This opinion has been strengthened with increase of experience. Opportunities have been afforded me of inspecting sources of supply in all parts of the kingdom, sources of the most diverse character and from every kind of geological formation from which water is obtainable. In numerous instances I have had to investigate supplies which have been the cause of outbreaks of disease, and in many others to investigate the cause of some change rendering the water objectionable in character. In nearly all such cases I have found that the examination of the source of the water afforded information without which the chemical, bacteriological, or microscopical examination of the water could not have been correctly interpreted.

In recent years bacteriology has come to the aid of chemistry, and there is now a general opinion that a bacteriological examination is more important than a chemical analysis. This is undoubtedly true in certain cases, but not in all. A properly made bacteriological examination may often afford indications of pollution which no chemical analysis could possibly detect, but I am afraid that the inferences drawn from the results of many so-called bacteriological examinations are often as fallacious as those derived from the results of chemical analyses. When we find that waters used for long periods by large communities are condemned by bacteriologists as being dangerously polluted, and that the results obtained from the same water by different bacteriologists differ to an extent which is impossible in a chemical analysis, our faith in bacteriological examinations is somewhat shaken. In any case a proper bacteriological examination is far more tedious and more troublesome to perform than a chemical analysis, and the results are even more difficult to correctly interpret.

The microscopical and biological examination of matters suspended in drinking water has never received in this country the attention it deserves. Very often such an examination reveals more quickly and certainly the character of a water and some defects in its source than either a chemical or bacteriological analysis. In several instances such an examination has led, in my practice, to the discovery of sources of pollution which had been overlooked at a careful inspection. I have endeavoured therefore in this book to give it the importance it deserves.

I have also been impressed with the desirability of making more complete chemical analyses. The ordinary methods adopted for the analysis of a water are sufficently simple and reliable for many purposes, although much more skill and care are requisite to obtain concordant and accurate results than is generally imagined. The great difficulty, however, does not lie in obtaining results, but in correctly interpreting them; this requires an extended experience and an intimate knowledge of everything connected with the sources of supply.

The more complete chemical analyses to which I refer are of importance both from the sanitary and scientific point of view. Such analyses have rarely been made in the past on account of the great skill required and the tediousness of the processes. During the last eleven years, however, I have devised and tested a series of processes which now enable me to make such an analysis in a reasonable time, and which yield results sufficiently accurate for all practical purposes. These methods are fully described in this book, and a considerable number of analyses are appended showing the difference in character of waters from different geological sources, and the variations in waters from the same geological source. It is to be hoped that in future years this list will be considerably extended, as it will render great service to the geologist and to everyone interested in our underground sources of water supply.

The chief object of the work, however, is to show how to examine sources of supply, and how to use the information thus acquired in the interpretation of results obtained from the examination of the waters yielded by these sources, and to demonstrate that it is more important to consider the quality than the quantity of the organic and inorganic constituents found in waters from whatever source derived. Standards may be useful to the beginner and the inexperienced, but are carefully to be avoided by the expert and experienced. They are chiefly advocated by those who have some 'process' or 'method' which they have devised and wish to commend, and so far all such processes have failed to stand the test of time. What is wanted is the application of common-sense to the subject of water examination. How can any analysis, however complete, tell us anything of the liability to pollution?

Some of the purest waters I have ever examined have been liable to occasional pollution of the most serious character.

The importance of the systematic inspection of all sources of water supply is now fully recognised by the Local Government Board, and the President has requested the Commission on Sewage Disposal to make a recommendation dealing with the whole subject of water pollution. As a result the Commission has, in an interim report, expressed the opinion that Rivers Boards should be formed throughout the country. In the course of their inquiries they have found that water supplies are liable to other serious pollutions besides those which can be dealt with under the Rivers Pollution Prevention Act; and although in the case of the larger water undertakings the owners may be desirous of doing all that is possible to safeguard their sources of supply, they are satisfied that there are cases where the supervision of some superior authority is desirable in the interests of the public health. Over the Local Rivers Boards there would be a central authority, probably a special department of the Local Government Board, whose function would be to exercise a general supervision over the whole country in regard to the prevention of the pollution of water, and with power to order the purveyors of water, or other responsible parties, to adopt such means as in the opinion of the Central Authority are reasonable and necessary for removing or diminishing the danger. There can be no doubt that ultimately this suggestion will be acted upon. In any case the opinion expressed confirms my views as to the importance of the systematic inspections of sources of supply. I do not wish to be misunderstood. I do not, for a moment, refuse to recognise the importance of chemical, bacteriological, or microscopical examinations of samples of water; I merely contend, that however great this importance, the examination of the source of supply is usually greater.

I am conscious of many imperfections in the book, but as it may serve a useful purpose, and covers ground not touched by any other work with which I am acquainted, I am emboldened to publish it.

I am greatly indebted to my friend Mr. PRATCHETT for the drawings made from water deposits, to my coadjutor Mr. M. PRIEST, F.I.C., and my assistants Drs. PUGH and SOWDEN for their help whilst the book has been passing through the Press, to the Editors of 'Hygiene' for their permission to reproduce Jordan's Table of Water Bacteria, and to Dr. GARRETT for the loan of the blocks for Plate XIX.[1]

PUBLIC HEALTH LABORATORIES,
LONDON HOSPITAL MEDICAL COLLEGE, LONDON, E.
*May* 1904.

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[1] Jordan's Table and Dr. Garrett's Plate have been omitted in this edition.

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# THE EXAMINATION
OF
# WATERS AND WATER SUPPLIES

## PART I

## *THE EXAMINATION OF SOURCES FROM WHICH WATER IS DERIVED*

## CHAPTER I

### SOURCES OF SUPPLY

The examination of the source from which a supply of water is derived is necessary for many reasons, and is in all cases imperative when the supply is to be utilised for domestic purposes. This applies equally to the sources supplying single houses and to those supplying large communities. Many serious outbreaks of disease might have been prevented had this advice been generally acted upon, as it has frequently required very little examination to prove that the waters causing these epidemics were bound at some time to become dangerously polluted. It is immaterial whether the water is derived from the ground surface, from the subsoil, from springs, from deep wells, or from rivers, everything possible should be known about the origin of the water, and every possible effort made to ascertain whether its character or purity is likely to be affected in any way before it reaches the consumer. These investigations in some cases are quite simple, but in others they require special skill and knowledge, and often tax the ingenuity of the examiner to the utmost. The various ways in which waters from diverse sources may be affected will be dealt with in the ensuing chapters, and the methods of investigation given in detail and illustrated by examples from the author's own experience.

When the supply is for domestic purposes, as is usually the case in these investigations, it is often more important to fully investigate the source of supply than to make chemical or bacteriological analyses of the water itself. The latter may indicate when a water is polluted and may on occasions indicate possibilities of dangerous pollution, but they cannot be relied upon.

Pollution is frequently intermittent, and a water, generally of great chemical and bacteriological purity but liable to occasional contamination, is eminently unsafe, either as a public or private supply. Moreover, there are limits to the powers of analysts to detect impurity, or, having detected it, to decide whether it is of an innocuous or positively harmful character. Obviously, therefore, no report on the safety of a supply can be complete without a careful examination of its source. This examination, supplemented by chemical, bacteriological, and microscopical analyses, will generally enable a reliable opinion to be given, as the results of the examination usually render possible a correct interpretation of the analytical results.

For the effective examination of the source of a water supply some knowledge of geology is absolutely necessary, as without this it is frequently impossible to locate the points at which impurities may gain access to the water, or to form an opinion as to whether a given source is adequately protected or not. There must be some knowledge of the nature and extent of the water-bearing stratum, and of the impermeable stratum below it, and also of that above it, if the supply is from a deep source. The locality and nature of any 'faults' must also be studied, together with the angle of inclination of the strata, the plane of bedding and the direction of the fissures in a rocky formation.

The geological maps of the Ordnance Survey are indispensable for this purpose. These maps are all on the scale of one inch to the mile. The 'solid' maps show the distribution of the solid rock formations, the 'drift' maps show the superficial deposits overlying them, the rock formation being coloured only where there is no drift. In parts of the East of England, where the superficial deposits are thick and widely spread, only the drift edition is published. From near Scarborough southward, over the east and south-east of England, the drift edition is the more useful for reference when considering the question of water supply, unless a supply from a deep source is contemplated, when the solid edition will be also required. For surface water supplies the ordinary maps, 6 inches or 25 inches to the mile, showing the contours and surface level at various points, are also required, as upon these the catchment or drainage areas can be delineated. The handbooks supplied with each set of maps must also be consulted, and the knowledge thus obtained corroborated and extended by personal exploration of the locality.

The following table, which enumerates all the more important strata found in the British Isles, from above downwards, is one which I frequently find useful for consultation, but it must be remembered that probably in no one locality do all these beds exist. Some are missing in one district, others in another; in certain districts some attain a considerable thickness, whilst in others they have so thinned out as to be unimportant. I have therefore appended a few notes to the more important formations, which may be of value, but they will frequently have to be supplemented by reference to advanced text-books on Geology.

SERIES OF BRITISH STRATA COMMENCING AT THE SURFACE

| | |
|---|---|
| POST-TERTIARY— | |
| | Alluvial deposits, blown sands, &c. |
| | Glacial and post-glacial sands and gravels, boulder clay. |
| TERTIARY— | |
| Pliocene | The crags (sands and shells) of Norfolk, Suffolk, and Essex. |
| Miocene | Almost unrepresented in Great Britain. |

Series of British Strata commencing at the Surface—(*continued*)

| | |
|---|---|
| Eocene | Sands, clays, marls, &c., with limestone in their beds. Hampshire and Isle of Wight.<br>Upper Bagshot sand.<br>Barton clay.<br>Middle Bagshot beds.<br>Bracklesham beds.<br>Lower Bagshot beds. Clays and sands.<br>London clay.<br>Oldhaven, Woolwich, and Reading beds and Thanet sands. |
| Secondary or Mesozoic— | |
| Upper Cretaceous | Upper chalk with flints.<br>Lower chalk without flints.<br>Chalk marl.<br>Upper greensand.<br>Gault. |
| Lower Cretaceous | Lower greensand, Folkestone, Sandgate and Hythe beds, and Atherfield clay.<br>Weald clay.<br>Hastings beds, Tunbridge Wells sand, Wadhurst clay, Ashdown sands. |
| Jurassic<br>Hard sandstones and limestone alternating with clay and shales. | Upper or Portland oolites.<br>Purbeck beds. Portland stone and sand.<br>Kimeridge clay.<br>Middle or Oxford oolite. Coral rag and calcareous grit.<br>Oxford clay. |
| Lower or Bath Oolite. | Great oolite. Cornbrash, Forest marble, Bath or great oolite, Northampton sands.<br>Fuller's earth.<br>Inferior oolite. Lincolnshire limestone, Northampton sand. |
| Lias | Upper lias (shaly clay), middle lias (argillaceous limestone, sands and clays), lower lias (as middle lias). |
| Triassic— | |
| Keuper | Red marl. Contains beds of rock salt and gypsum.<br>Keuper sandstone. |
| Bunter | Upper mottled sandstones.<br>Pebble beds.<br>Lower mottled sandstones. |
| Permian— | |
| Upper Permian | Red sandstone, clays and gypsum.<br>Magnesian limestone.<br>Red and variegated sandstone. |
| Lower Permian | Red sandstone, marl, breccia, and conglomerate. |

Note.—The Permian and Triassic series are often included in one group as the 'New Red Sandstone.'

Series of British Strata commencing at the Surface—(*continued*)

| | |
|---|---|
| Primary or Palæozoic— | |
| Carboniferous . . . | Coal measures. Sandstones, clays, coal, shales, flagstone and ironstone. |
| | Millstone grit. |
| | Sandstones with thin seams of shale, coal, and limestone. |
| | Carboniferous or mountain limestone. |
| | Yoredale rocks (limestone chiefly). |
| | Limestone and shales. |
| Old Red Sandstone . | Red sandstones, shales and conglomerates. |
| Devonian . . . . | Grey slate and limestone. |
| | Grey unfossiliferous slate. |
| | Soft slate with bands of limestone and sandstone. |
| Silurian . . . . | Ludlow rocks. Sandstone, limestone, shale. |
| | Wenlock limestone and shale. |
| | Llandovery shale and sandstone. |
| Lower Silurian . . . | Shales, slate, sandstone, &c. |
| Cambrian . . . . | Slates, sandstones, &c. |
| Eozoic— | |
| | Gneiss and crystalline schistose rock. |

**Post-tertiary Sands and Gravels.**—These superficial deposits are more widely distributed than any older stratum, and vary in thickness from a few inches to 150 or even 200 feet. Most shallow wells are sunk in this drift, and the water therefrom varies much in character in different localities. Usually on the same gravel patch the unpolluted water is fairly uniform in character, and samples of such must be taken as standards with which to compare water obtained from other portions. Care must be taken in selecting typical wells or springs for this purpose that the water does not come from the direction of a village or farmyard, or other such possible source of contamination. Springs are common at the edges of these patches, but they are rarely of any magnitude.[1]

**Boulder Clay.**—In some districts this clay attains a thickness of 150 feet or more. It is not absolutely impervious. It usually yields a very hard water, and this sometimes has an odour of sulphuretted hydrogen. Water is often said to be derived from the boulder clay when it actually comes from an earlier drift of sand lying immediately beneath it.

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[1] In chapter xviii will be found a series of analyses of waters from various geological sources.

**The Crags of East Anglia.**—These shelly sands are very limited in area, and yield comparatively little water. Very often they are impregnated with sea-water, and occasionally they are ferruginous. Springs are comparatively rare.

**The Bagshot Sands**, found in the Isle of Wight, capping many hills near London, and forming the Frimley and Chobham Ridges, the heaths of Bagshot, Hartford Bridge, and Sandhurst, usually yield a soft water, which is sometimes ferruginous. Many patches yield water containing little or no calcium carbonate, and acting markedly on lead, zinc, and iron. Round the edges of patches of these sands the water oozes away, and springs are numerous but small. In the London Basin this formation varies from 100 to 350 feet in thickness, and extends over an area of more than 200 square miles.

**London Clay.**—This bed attains a thickness of 450 feet, but thins out completely at the edges of the Basin. It is very impervious, yet in places the upper surface has become loamy, and shallow wells sunk in this loam may yield a little water. In these cases the clay is usually found intersected with laminæ of crystals of gypsum, and the water is excessively hard; it may also contain a considerable quantity of salt.

**Oldhaven, Woolwich, and Reading Beds.**—These lie at the base of the London clay, and as a rule yield little, if any, water, but I believe that in some cases a considerable quantity of water enters deep wells from these beds. Such waters are highly charged with magnesium salts.

**The Thanet Sands** consist of an argillaceous greyish greensand, of variable thickness. Under London they are about 20 feet thick, in West Kent over 60 feet. The outcrop has a very limited area, and I know of no springs arising therefrom. The yield of water is very variable. Some bored wells yield about 100,000 gallons per day. The sand is so fine that bore tubes are easily silted up, but by means of the recently introduced air-lift pumps water can be obtained more freely than is possible with the pumps usually employed. Save near the outcrop, the water is soft and alkaline, and identical with that yielded by the chalk beneath. This is not surprising, since there is no impervious stratum between the two. Near the Essex coast the water is often hard, and contains much magnesia, and at some places farther inland the water is even more highly charged with salt and magnesium and calcium sulphates. As I have shown elsewhere[1] there is an infiltration of sea water into the chalk and Thanet Sands at many points, but in localised areas the lower London Tertiaries yield waters containing more saline matter than can be accounted for by such infiltration.

**Chalk.**—'The chalk extends from Flamborough Head inland, forming the Yorkshire Wolds, and thence running beneath the Humber near Hull to form the Lincolnshire Wolds. It constitutes the foundation of the greater part of Norfolk and Suffolk, but is in these counties very much concealed by glacial drifts, and does not there appear in such conspicuous hills as those which extend from Royston and Luton Downs to the Chiltern Hills, the Marlborough Downs, and Salisbury Plain. Thence the chalk stretches out irregularly to the west beyond Dorchester, and is found in outliers near Chard, Seaton, and Sidmouth. Eastward of Salisbury Plain the chalk forms a large extent of Hampshire; it is found in the Isle of Wight, and borders the Wealden district, forming the cliffs from Margate to Folkestone on the north and those from Beachy Head to Brighton and Littlehampton on the south. It is also exposed at Gravesend and Grays Thurrocks' (Woodward). In the London Basin it extends over an area of upwards of 2000 square miles, and has a thickness in places amounting to 1000 feet. It is probably the most important water-bearing stratum in this country. The water chiefly travels through fissures, hence polluting matter may be carried very considerable distances. Swallow-holes are common in the chalk and often lead to the pollution of wells. Water is obtained from the chalk by shallow and deep wells, and by driving adits to cut a number of fissures. Springs are numerous, and often yield enormous quantities of water. Along the outcrop of the gault the springs are not so large as those derived from the chalk where it has passed deeply under the London clay, and again become exposed at or near the sea level.

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[1] *The Essex Naturalist*, 1912: 'The Alkaline Waters of the London Basin.'

The waters derived from the chalk may be divided into two classes—the calcareous and the alkaline. The former are usually 'hard,' but the hardness is chiefly 'temporary'; whilst the latter are very soft, and contain sodium carbonate. The 'alkaline' waters only occur where the chalk lies buried beneath a thick mass of London clay, in all other places the water is 'calcareous.'

Pure chalk water is especially characterised by its palatability, its brilliancy and freedom from colour; but in some districts in East Yorkshire, Norfolk, and Suffolk, it is not unusual to find it containing so much ferrous carbonate as to be unfit for use without prior chemical treatment to remove the iron. These waters are merely dull and yellowish when first drawn, but speedily become turbid and brown when exposed to air.

**Upper Greensand.**—The chalk marl is often so impervious as to separate the water in the chalk from that in the upper greensand. This formation is but little developed near London, but becomes of importance in Wiltshire. At White Nore Cliff, in Dorsetshire, it has a thickness of 100 feet. It averages 60 feet in thickness in the Wealden district. 'At Petersfield it is 80 feet, at Eastbourne 40 feet, at Godalming 50 feet, and at Nutfield 40 feet. It is exposed north of Folkestone and at East Wear Bay with a thickness of less than 20 feet. It is essentially a water bearing stratum' (Woodward). The water varies much in character, but is usually markedly calcareous, and in certain localities it is ferruginous.

**Lower Greensand.**—The upper and lower greensand are separated by the gault, a stratum of clay 100 to 200 feet in thickness. The outcrop extends from Folkestone, in a band of varying width, westward through Ashford, Maidstone, and Reigate to Farnham. It then trends southward to Petersfield, and finally eastward to the coast at Eastbourne. The southern half of the Isle of Wight is in great part formed of the lower greensand. There is a limited outcrop near Leighton Buzzard, to the North of London.

The total area of the lower greensand in the London Basin is about 500 square miles, and its thickness is from 200 to 500 feet. The Folkestone beds are very ferruginous. At Reigate the sands attain a thickness of 450 feet, in Bedfordshire 250 feet. In both cases the dip is towards London, yet this stratum is apparently absent under the Metropolis, as borings have failed to find it. Springs are not numerous in this formation, but there are copious springs arising from the greensand near Sevenoaks, Dorking, Weston Street, and Farnham, the water being doubtless thrown out at the outcrop of the Weald clay. The Royal Commission on Water Supply (1869) reported that the water from the lower greensand was ‘ excellent for all domestic purposes, being bright and limpid, of a degree of hardness varying only from 3° to 9° of Clark's test, and generally very free from organic matter.'

There are very many exceptions, however, to this rule. Unfortunately also these sands often yield a water containing an amount of ferrous carbonate which seriously affects its utility for domestic purposes.

**Hastings Beds.**—These are separated from the lower greensand by the Weald clay. This and the Hastings beds constitute the Wealden beds, found in Surrey, Sussex, Kent, and Dorset and the Isle of Wight. The total thickness of the Wealden beds is said to be 1500 feet. The Hastings beds consist of sands with intercalated beds of clay, which sands receive different names according to the locality in which they are most developed. In order from above downwards the two chief divisions are the Tunbridge Wells sands and the Ashdown sands separated by the Wadhurst clay. The Tunbridge Wells sands at Tunbridge Wells have a thickness of 180 feet, but elsewhere they may have a much greater depth. The Ashdown sands may obtain a thickness of 500 feet, and yield more water than the Tunbridge sands. The Tunbridge Wells supply for example is derived from the Ashdown sands, and the boring pierces the Wadhurst clay. All these sands are more or less ferruginous and the water derived therefrom often contains so much iron as to necessitate special treatment to render it usable. The water is usually soft and, so far as my experience extends, often contains sodium carbonate, resembling in this respect the alkaline waters from beneath the London clay.

**The Upper and Middle Oolites** contain permeable beds which, however, give rise to no considerable springs and are only of local importance as sources of water supply.

**The Lower Oolites** is separated from the Middle Oolite by the Oxford clay, which varies in thickness from 300 to 600 feet. This clay contains calcium carbonate and iron sulphide (pyrites). The Great Oolite (Lincolnshire, Northamptonshire, Gloucestershire, and Oxfordshire) is from 250 to 300 feet in thickness and consists of beds of shelly limestone and marly clay. Within the Thames Basin they have a collecting area of about 300 square miles, and give rise to numerous fine springs. The water is usually thrown out by the outcrop of Fuller's earth. Below the Fuller's earth is a series of beds, the most important of which is the Lincolnshire Oolite, which, in that county, attains a thickness of 200 feet. It thins out towards Kettering. This inferior oolite and the underlying sands are about 320 feet thick in the neighbourhood of Cheltenham, and thin off, to disappear under Oxfordshire. It follows, therefore, that a good deal of water is imprisoned in these strata, although springs of considerable volume are common at the base of the hills of this formation. The water naturally contains much calcium carbonate, and in all respects resembles water from the superficial chalk. Where the water is imprisoned, however, it undergoes an entire change of character, becoming alkaline, thus resembling the water from the deep chalk of Essex and London.

The oolite probably rivals the chalk as a source of water supply, both in quality and quantity. There is greater danger, however, of polluting matter being carried long distances, as from the compact character of the limestone the water can only travel through and accumulate in its fissures.

**The Lias** 'forms a conspicuous band stretching across England from Whitby and Redcar, on the coast of Yorkshire, to Lyme ~~Regis,~~ on the coast of Dorset, the harder rocks forming gentle escarpments which overlook the vales formed in the softer or clayey strata' (Woodward). It consists of beds of clay, shale, limestone, and marlstone. In certain districts this formation yields a considerable quantity of water, and springs of large volume are not infrequent. The water is usually very hard, but most of the hardness is easily removable by boiling.

**The Triassic Rocks (New Red Sandstone)** 'form part of the plain of York, and stretch through Nottinghamshire, Lincolnshire, Derbyshire, Cheshire, South and East Lancashire, Staffordshire, Warwickshire; Worcestershire, and Gloucestershire, and there is an outlying mass near Carlisle' (Woodward). These strata are of very great importance as a source of water supply, ranking next to the chalk and oolites. An immense number of shallow wells are sunk in them, and many towns are supplied with water from deep wells and springs in these formations. The sand granules of which they are composed are cemented together by calcium sulphate and carbonate; hence the water is usually very hard, and much of the hardness may not be removable by boiling. The hardness is also often due, in part, to the presence of magnesium salts. In the neighbourhood of salt deposits the water may contain much salt, elsewhere the chlorides are very low. The unpolluted waters from this formation are usually clear, bright, colourless, palatable, and wholesome, well adapted for all domestic purposes except washing, for which most of them are too hard.

In sinking wells in this formation the water in various fissures may differ greatly in character. In one well sunk near Warrington no less than three different kinds of water were found, one being exceedingly hard and rendering the others unfit for domestic purposes. When this was located and stopped out a water of unusual excellence was obtained.

**Permian Series.**—The sandstones of this series are sometimes included in the term 'New Red Sandstone' or called the Lower Red Sandstone. The sandstone occurs in Yorkshire, west of Doncaster; in Cumberland, at St. Bees' Head and Corby Castle; in Durham, at Claksheugh; in Lancashire, at Astley; also at Penrith, around Wolverhampton, south of Shrewsbury, west of Birmingham, and around the Dudley coalfield. The water obtained therefrom resembles that from the New Red Sandstone proper.

**The Magnesium Limestone or Dolomite** has a thickness of 300 feet in Durham, and this thickness is maintained to Pontefract, the series gradually diminishing in thickness to about 120 feet near Annersley, South Notts (Woodward). The water is usually very hard, and the permanent hardness is sometimes considerable.

**Coal Measures.**—These are not important water-bearing strata, although immense volumes of water are often pumped from coal mines. The water varies greatly in character, but usually it is too hard and contains too much saline matter to be suitable for domestic purposes.

**Millstone Grit.**—This formation consists of coarse and fine sandstones, shales, and conglomerate, which crop out at the edge of the coalfields, from South Wales to the middle of Scotland. In Lancashire the Millstone Grit contains thin coal seams and is estimated to have a thickness of from 3500 to 5000 feet. It is comparatively unimportant as a source of water supply, being too dense and impermeable. Springs arise from fissures, and in a few places water is obtained from deep borings. The water varies much in character, but is usually moderately soft.

**Mountain Limestone.**—The carboniferous or mountain limestone is a very extensive formation, rich in mineral veins, forming the axis of the Pennine Chain. The stratum is much fissured, and springs occur of all volumes from a mere trickle to a decided river. The river Aire arises from springs near Malham. The fissures are sometimes so large and contain so large a volume of flowing water as to constitute underground rivers. Usually the water is very clear and palatable, but it is often too hard for domestic purposes. Occasionally the water is discoloured by peat, and not infrequently it contains traces of iron. The water is notoriously liable to contamination on account of the size of the fissures and the abundance of 'swallow holes.'

**Old Red Sandstone.**—This formation extends from near

Bridgnorth in Shropshire, southward, through a considerable portion of the counties of Hereford, Monmouth, and Brecon into Glamorgan, Carmarthen, and Pembroke (Woodward). It contains very little soluble matter, and therefore as a rule the waters obtained from its fissures are moderately soft and well adapted for domestic purposes.

**The Devonian** slates and limestone occur in West Somerset, Devon, and Cornwall, the Silurian and Cambrian rocks in Wales and the Lake District, and the Eozoic rocks are probably represented at Malvern, Charnwood Forest, Anglesea, Holyhead, and the adjacent parts of Carnarvonshire. These rocks are very hard, impervious, and insoluble ; hence such water as may be found in fissures, or which issue therefrom as springs, contains very little saline matter and is usually very soft. Comparatively little water is obtained from the rocks, but from their surfaces enormous quantities of water run off rapidly, and, filling hollows in the mountains, form lakes, several of which are now being utilised for the supplies of cities long distances away. Of the Igneous rocks, granite is the only one which occurs over any extended area. In the south-east of Ireland there is a mass of granite 70 miles in length and from 7 to 17 miles in width. Large intrusive blocks of granite occur in the south of Scotland and in Devon and Cornwall.

With reference to matters geological, the most useful works to consult are Woodward's ' The Geology of Water Supply,' and the same author's ' Geological Atlas of Great Britain.'

The geological edition of the maps of the Ordnance Survey includes sections in various directions, showing the thickness of the strata, the known faults, &c., and the ' Handbooks ' and other publications give all the well sections which could at the time of the survey be obtained. Frequently local Field Clubs and Natural History Associations issue ' Transactions ' containing information of the utmost value. Often also there are persons interested in local geology who can supply useful data ; but beware of the oldest inhabitant, as his uncorroborated testimony is rarely to be trusted.

In examining water supplies some knowledge of engineering is also necessary in order to know what points should receive attention when examining wells, storage and service reservoirs, water mains, hydrants, sewer-flushing arrangements, &c. It must at least be assumed that the reader has made himself thoroughly acquainted with the matters dealt with in my work on 'Water and Water Supplies.'

Important as the inspection of a source of supply may be, we cannot afford to ignore the information which may be obtained by analyses, chemical and bacteriological, of the water itself and by the microscopic examination of any sedimentary matter found in it. These analyses will indicate whether the water is of a satisfactory or unsatisfactory character, and if a series of analyses is made variability will be detected, and the careful study of the results may afford a clue leading to the discovery of some unsuspected source of danger if such exists. On rare occasions a water may be found of such a character as to be considered unsafe for domestic purposes, yet no possible source of pollution be discovered upon examining its source. In many instances in which analyses have indicated pollution, defective sewers, unsuspected cesspools, &c., have ultimately been discovered when a thorough examination has been made. Such causes of pollution could only be detected by excavations around the source of the supply, which would never have been made had not the analytical results indicated 'danger.'

When supplies are derived from wells, superficial or deep, it is requisite that analyses should be periodically made and the results recorded, especially if the wells are within a short distance of human habitations, farms, or sewers. If a record of the rainfall is kept, any disturbing influence due to this cause will speedily be detected. In the cases where waters are derived from sources known to be polluted—such as contaminated rivers, which sources would be obviously unsafe were the water not properly collected, stored for sedimentation, and filtered—it is necessary that the various processes of purification be carefully supervised and that samples of the water derived from the filters be examined bacteriologically at frequent intervals.

It follows, therefore, from what has been said, that under one set of circumstances analyses of a water are of more importance than examinations of its source, and under others that the examination of the source is the more important. In very few instances can either the one or the other be entirely ignored.

As I regard the inspection of the source as being of primary importance, I purpose dealing with this subject before referring to the analyses, more especially as it is, in nearly all cases, necessary to know something of the source of a water if the results of the various analyses are to be correctly interpreted.

# CHAPTER II

## EXAMINATION OF SHALLOW AND DEEP WELLS AND SPRINGS

Only a very small percentage of the shallow wells in this country are either satisfactorily placed or properly constructed, and often a most cursory examination is sufficient to show that pollution is possible. In other cases a more detailed survey is necessary, including the opening of the well and possibly of the ground in the vicinity, to search for drains, cesspools, &c., within the drainage area. The extent of this area depends upon the nature of the subsoil, upon the depth of the well, upon the depression of the water level produced by the abstraction of the maximum amount of water required per day, and upon the direction of flow of the ground water. This applies to all shallow wells, that is, to all wells sunk in a superficial permeable stratum, whatever the depth.

The more porous the subsoil, the larger the drainage area or area of depression produced by the abstraction of water and *vice versa*. In no case is it safe to regard this area as less than the area of a circle the radius of which is twenty times the depression of the water level produced by pumping, and in running sand and fissured rocks it may be greater. If, for example, the depression produced is only 1 foot, the drainage area should be taken as extending over a radius of not less than 20 feet from the well as the centre. When the ground water surface has a marked slope, the portion of the drainage area which most requires protection is that where the water level is highest. The surface of the ground water round a well when depressed by pumping has the form of an inverted cone, the sides near the well being steep and gradually rounding off into the nearly horizontal surface of the subsoil water. The velocity of the flow of the water towards the well at any point varies with the distance of that point from the well, the velocity decreasing more rapidly than the inverse of the square of the distance. For example, if within 3 feet of the well the movement of the water is at the rate of 3 inches per second (probably a higher velocity than ever occurs through any porous stratum), at 30 feet it could not be more than 1 foot in 400 seconds, and at 90 feet the rate would be less than 1 foot in an hour. At a certain distance from the well, therefore, the movement of the water through the soil is slower than the rate of filtration through sand in any artificial system of purification. This, of course, applies only to a subsoil of uniform character.

The depth of the well, or rather of the ground water, should also be considered, since the nearer this approaches the ground surface the greater the risk of contamination. Where the water level when at its highest is only 2 or 3 feet from the ground surface it will be almost impossible to render the water safe unless the whole of the area of depression is protected. Where the highest point reached by the ground water is 60 or 70 feet from the surface, and the ground is compact, percolation will be so slow that purification is ensured before water from the surface reaches this level. In such a case a very limited protective area is necessary.

As an example of the method of determining the extent of the area to be protected, suppose that in a sandy subsoil, with a ground water level at its highest several feet from the surface, a well is sunk from which 45,000 gallons per day are abstracted and that the maximum depression produced is 9 feet. Each foot of saturated sand yields about 1½ gallon of water. To yield 45,000 gallons, therefore, 30,000 cubic feet of the subsoil would be drained. The volume of a cone being the area of its base multiplied into one-third of its height, it follows that if the volume be 30,000 cubic feet and the height 9 feet, the area of the base of the cone of depression would be (assuming the sides to be straight) 10,000 square feet, representing a circle with a radius of 57 feet. The cone, however, has not straight but curved sides, yet for all practical purposes the cone is included in the area above given, since beyond that radius the flow of water becomes so slow that efficient filtration must result. A protective area of 20 to 30 yards' radius, kept free from all polluting matter, would probably suffice to render the water from this well quite safe, but it would undoubtedly be better to have an outer protective zone either uncultivated or simply laid down to pasture.

This so-called cone of depression is often purely imaginary. When actual tests are made by driving tubes round a well, it is in my experience the rule to find that the water level is markedly depressed in one direction and scarcely affected in others. Even in fairly compact sand and gravel beds there are lines of least resistance along which the water flows, and this direction may be very different to that anticipated from the contour of the locality. An excellent example of this is recorded on p. 35 relating to the examination of a spring at Great Baddow near Chelmsford. For this reason it is always desirable to have a much larger protection area than the calculated area of the cone of depression, and the Local Government Board usually insists upon a protection area of 8 to 10 or 11 acres according to the position of the well or spring and the amount of water derived therefrom. The inner zone should be kept free from rabbit runs and from animals of all kinds, but the outer zone may be used as grazing land.

Where the ground is fissured it is impossible to define the protective area, but the directions of the fissures and of the flow of water therein should be determined and particular attention paid to the ground above the well where the fissures come to the surface. If the well is fed by underground drains, the depth and direction of these should be ascertained, and the whole of the area drained should be examined for evidence of the presence of polluting matter. In or near towns and villages, and near farmyards, the whole of the water in the subsoil over an extended area may have become polluted. In such a case it is useless to expect to obtain a supply of wholesome water from any shallow well, however carefully constructed or protected.

Unfortunately fissures may extend very considerable distances and in entirely unexpected directions. For example, I recently examined a public water supply, derived from a shallow well with adits in the mountain limestone formation, the water from which suddenly became turbid and contained various low forms of animal and vegetable life such as are usually found in ponds. Fluorescin experiments made in fissures higher up the valley failed to show any connection between these and the well, but inquiry led to the discovery that the onset of the turbidity coincided with the letting off of the water from an artificial lake in an adjoining valley, and an examination of this valley showed the presence of certain swallow holes down which the whole of the water from the lake disappeared, only to reappear a few hours later in one of the adits of the well, a mile or so away, in an entirely different valley. The water in its course passes under a hill of considerable elevation.

In examining a water supply from the subsoil the well should be opened out to ascertain how it is covered and constructed, and how the pump pipe or rising main enters; the condition of the sides should be examined to ascertain if there are traces of water entering from near the surface, or whether the rootlets of trees have penetrated into the wall. The depth of the water from the ground surface, the depth of the water in the well, and the depression caused by pumping may then, if desired, be ascertained. Samples of water taken respectively from near the surface and near the bottom of the well may upon examination give information of importance. If water is observed entering at more than one point, samples from each may be collected and compared. If the pump is defective, the well may be polluted by water used for priming. I have seen ditch water poured into the pump cistern for this purpose under the impression that the first few strokes of the pump, when in action, would remove all the impurities. That such is not the case can easily be demonstrated by priming the pump with a solution of permanganate of potassium. It will be found that the whole of the water in the well has become tinted, and it may be days before the colour disappears. (For construction of shallow wells, *vide* end of this chapter.)

In deep wells—that is, wells bored through an impermeable stratum to water-bearing rocks beneath—pollution is chiefly to be sought for near the surface, and the upper portion of the well and the surface of the ground require examination, as in the case of a shallow well. If the outcrop of the water-bearing stratum is under the sea, indications of sea-water infiltration must be sought for in the saline constituents of the water, and by comparing the results obtained from the analyses of samples taken when pumping has ceased for a time with others of samples taken after long-continued and heavy pumping. If the outcrop is at no great distance possible sources of pollution should be sought for upon it.

The analytical results will often give a clue to the source of pollution.

For example, a deep well in the chalk, water from which I examine at regular intervals, had recently shown signs of change, the free ammonia increasing. Careful examination of the water showed a marked increase in the sulphates, which led me to suspect gas liquor. A test for sulphites showed that these were also present and a somewhat doubtful reaction for sulphocyanates was obtained. Upon going down one of the wells a distinct odour of gas was observed, all of which pointed to the source of contamination, a gasworks in the immediate neighbourhood.

In another instance the bacteriological examination showed, too frequently, the presence of sewage or manure derived bacteria which led me to suggest a careful examination of the surroundings of the well, which was the sole source of supply to a town. It was then found that there was a stable yard in the vicinity, which was littered with manure and not properly drained. The manure was removed and also the polluted earth and the yard covered with an impervious layer of cement. A month afterwards the objectionable bacteria had disappeared and have not been found in the water since. The well was some hundreds of feet in depth, well lined, but in chalk throughout. Had there been a yard or two of clay on the top of the chalk doubtless pollution would not have occurred.

The mere presence of an impervious stratum, however, must not be accepted as proof that pollution is impossible. A disused well perforating this stratum may have been converted into a cesspool. Of this I have known several instances. Or there may be underground workings of marble, stone or minerals, the adits of which approach the well and which may be liable to pollution. All these possibilities must be borne in mind when reporting upon the water supply from any deep well.

In small supplies, whether from deep or shallow wells, where the pump is fixed over or near the well, the condition of the paving and ground around and the nature and condition of the arrangement for conveying away the waste water require examination. I have seen a well placed in a recess used frequently as a urinal, and the paving was so defective that the polluting matter could readily gain access to the well. The position of all drains, cesspits, cesspools, &c., should be noted, and their condition ascertained. If there is reason to believe that any such are within the drainage area of the well, the supply cannot be considered safe unless these drains, &c., are actually known to be perfect. Some time ago I had occasion to examine the water supply to a large house where typhoid fever and diphtheria had occurred. The water had been examined on several occasions by analysts and pronounced satisfactory. My suspicions were aroused by the very excessive amount of nitrates present, although in every other respect the analytical results were satisfactory. Upon tracing the main drain it was found to terminate in a large cesspool, hitherto unsuspected, within about 10 feet of the well. The cesspool was immediately at the back of a dairy and the well just in front. The cesspool was abolished and the drains diverted. Very soon afterwards, the well for the first time failed. This is an instance of the marvellous purifying action of the subsoil, as there was no doubt that the well had been chiefly fed from the cesspool, which had no outlet. The cesspool was acting as a perfect septic tank and the ground around as an ærobic filter. Quite recently I had to report, after a chemical examination, very unfavourably on a water from a deep well supplying a village. The well was within about 50 yards of a churchyard, but I was assured that the water came from the Thanet sands beneath the London clay, which at that point was of considerable thickness. Upon opening the well the upper 10 feet was found to be constructed of brickwork well rendered in cement and perfectly sound, but immediately below there were signs of water entering through the interstices between the unsteyned bricks. I had the well pumped out and the top of the bore tube exposed. A sample of water was taken from the tube at a considerable depth and found to be perfectly satisfactory, and entirely different from the water pumped from the well. There was found to be a considerable amount of alluvium above the clay, and from this the impure water was pouring into the well. At the rectory in the same village the water from the deep well was ascertained to be polluted, by pouring paraffin oil on the ground by the side of the suction pipe, as the exact position of the well was not known. In a day or two the paraffin had given its flavour to the water, and impurities were found to have reached the well from the kitchen drain along the track of the pump pipe.

In waterworks where the large pumps are placed in the well, sufficient care is rarely taken to prevent the access of dirt, grease, &c., and I have found the stages covered with greasy sawdust and greasy waste. From 'slip' or other causes water often washes such filth into the well and contaminates the water. I have traced the bacillus coli in such waters to the dirt carried down by the men's boots, which dirt becomes detached on descending the ladders and drops into the well. Occasionally, however, objectionable bacteria are found, the presence of which cannot be accounted for with certainty at the time, but which may be explicable later. Some time ago I was sorely puzzled with the results obtained from the examination of the water from a deep well, but I got upon the track of the mystery by the detection of some short hairs in a sample of the water. The well was opened and the pump barrel examined, resulting in the discovery of the remains of a rat. It had evidently been drowned in the well, got into the pump—the rest can be imagined. It has often struck me since, that such occurrences may be far from rare and explain results which are regarded as mysterious.

In another case a very deep well in the new red sandstone was found to contain too many bacteria and some of an objectionable type. I examined the works and found the water was first raised into a large tank under the engine-house floor and from this pumped to the service reservoirs. The floor of the engine-house consisted of iron plates, and every time these were swept a quantity of dust fell into the tank below. An examination of the tank showed that it was in a filthy condition. After it was cleaned out and properly enclosed, the water became of the highest degree of bacterial purity.

In several instances where public supplies have been stated to be dangerously polluted, I have found some local cause of contamination which had so affected the water as to lead the analyst to suspect or even to affirm that it was polluted by sewage.

Wells on low-lying ground liable to flood require careful protection, and special construction. If after a flood the water from the well is turbid, danger is indicated. If the flood water is from a tidal river, the water may become brackish. Since the damage to certain of the sea walls along the banks of the tidal streams in Essex, many deep wells have been ruined by the access of salt water. A rise and fall in level of the water in such a well synchronising with the rise and fall in the tide indicates a somewhat free communication between the well and the river or sea. This may or may not be dangerous in character, depending greatly upon the pollution or otherwise of the tidal water and the extent of the depression caused by pumping.

When the water in a well becomes turbid after heavy rain there is obviously some defect which requires prompt attention, since if coarse particulate matter can be washed into the well, pathogenic organisms, if present, could get in also. A few years ago an outbreak of typhoid fever occurred in a small town in Essex. It was limited to persons who obtained water from a tank or well which discharged the water through a small stand-pipe lower down the road. The Medical Officer of Health sent the water to an analyst for examination. It was clear and bright, and gave such good results upon examination that the chemist not only declared it good, but went out of his way to say that it could not possibly have caused typhoid fever. As other cases occurred amongst the users of this water, I was consulted, and soon obtained evidence that the water had recently become very turbid after heavy rain. Fortunately a similar downpour occurred within a few days, and a sample of the turbid water was sent to me. There could be no question of its impurity. The District Council, somewhat reluctantly, gave orders for a thorough examination of the source of the water, and it was then found that the drain from the Isolation Hospital, in which there had been a case of typhoid fever some weeks prior to the outbreak, was defective at a point close to the source of the water. The defect was a break across the top of the drain, and when the drain became nearly full the contents got into the ground around and could be traced to the well.

Abyssinian tube wells require that the ground surface around should be protected. Such a well sunk in the middle of a garden, where the subsoil water level is only a few feet from the surface, cannot be expected to yield a pure water. The tube is generally shaken by the action of the pump, and impurities may gain access through the loosened soil round the tube. The pump should be firmly fixed, the ground immediately around rendered impervious, and a proper arrangement made for conveying away the waste water. If there are doubts about the satisfactory character of the surroundings, pour a solution of fluorescin around the tube or where the defects are suspected, and follow this with water as fast as the ground absorbs it. Collect samples from time to time during a few hours' practically continuous pumping and examine. The solution is often found to be easily driven down by the atmospheric pressure, when pumping is going on.

Where deep-bored wells lined with tubes are used and the tube forms the suction pipe of the pump, there is danger of insuction of subsoil water if the tube is defective. The action of the pump is to withdraw the atmospheric pressure from within the tube, and the external pressure will force air or water through the most minute defects, through apertures so minute that under ordinary circumstances neither would have passed. When this action has once been set up, the openings are bound to increase in calibre, and insuction becomes still more easy. To detect such insuction depress the water-level as far as possible by continuous pumping, then pour a solution of fluorescin into a cavity dug round the bore-tube. Continue the pumping and examine in a litre flask or large colourless glass bottle samples of the water raised from time to time. After such continuous pumping, the water should be examined occasionally for some days. In an investigation of this character made by Dr. G. Turner, at the Suffolk Asylum, a solution of chloride of lithium was used, and the insuction proved by the detection spectroscopically of lithium in the water raised by the pump.

In tracing such connections and for discovering defects near the upper surface of a well, and along the track of the pump pipe or rising main, it is sometimes advisable to use solutions which, either on account of their colour or taste or chemical properties, can be easily identified, even when very largely diluted with water. A strong alkaline solution of fluorescin is very useful for this purpose, as also is paraffin oil, which penetrates the soil rapidly. If either of these liquids is poured in some quantity on the ground round the top of the well and over the track of the pump pipe, it can easily be seen when it begins to trickle into the well, provided the well is opened out and illuminated. The more quickly the advent of the test liquid, the more free is the opportunity for pollution. As the liquid becomes absorbed by the ground, buckets of water should be used to wash it downwards. If the test liquid does not make its appearance in the well until after the lapse of many days, it is probable that the filtration efficiency of the ground would be sufficient to ensure safety. If the well is not opened, water must be drawn from it from time to time and examined. In such a case I prefer to use a solution of fluorescin in brine, as the liquid, being denser than the water in the well, tends to sink, and is more quickly diffused through the water in the well. It is an advantage also to keep the water-level depressed as low as possible during the whole period of observation. This facilitates the entrance of impurities, and renders them more easy of detection, since the volume of water in the well is reduced. I recently examined a well in a garden adjoining a private house. The top of the well was covered with a large stone slab just above the ground surface, and the pump was fixed over the slab, rendering it difficult to open the well. It was upwards of 30 feet deep, and the water-level was some 25 feet below the ground surface. The subsoil was brick earth over sand and gravel. The water upon analysis was found to be very hard, to contain a large amount of nitrates, but very little organic matter as indicated by the ammonias and oxygen absorbed. As the ground was manured right up to and round the pump save at one point, and the stone covering was shaken every time the pump was used, I did not regard the arrangement as satisfactory. A solution of fluorescin was poured all around the pump, and followed from time to time by pailfuls of water pumped from the well. In thirty-six hours the tint of the fluorescin was quite evident in the water derived from the pump.

Common salt alone may be used, several pounds being spread over the ground surface, and water poured over it from time to time. The amount of chlorine in the water prior to the experiment being known, any marked increase will probably be due to percolation of the brine. It must be remembered, however, that the amount of chlorine in shallow wells often varies considerably from time to time and at different depths. Some time ago I examined the water from a shallow well, and found that the chlorine in a sample from the surface was small in amount, whilst in that from the bottom it was very excessive. In a deep well I found on one occasion a difference corresponding to over 300 grains of chloride of sodium per gallon. The water from the borehole was brackish, whereas that from the surface was rain-water, which drained from the paved yard into the well. The inferences to be drawn from variations in the character of a water at different times and at different levels are not always obvious, but an explanation should always be sought.

An interesting instance, whereby the source of the polluting matter entering a well was traced by aid of salt, is given in Dr. Page's report to the Local Government Board on an outbreak of typhoid fever at New Herrington, Durham. The well was sunk in fissured strata, which outcropped some three-quarters of a mile away. Upon this outcrop there was a farm, the sewage from which disappeared through some of these fissures. When the well was examined it was found that the walls were not impervious, and that a small feeder entered on the south side at a distance of 45 feet from the surface, issuing from the brickwork at a rate of 22 gallons per minute. A sample from this 'feeder' upon analysis gave indications of organic impurity, and the chlorine per gallon was 3·4 grains, as compared with 2·2 grains in the well water. In looking round for the probable source of this water, Dr. Page visited the farm above mentioned. He says: 'The farmhouse and buildings are upon the magnesium limestone, the beds of which dip towards the north. Owing to subsidences caused by the colliery working below, fissures extending to the surface exist in the locality. The drainage of the farm buildings, of a cottage, and of the farmhouse itself (in which latter there is a water-closet) is conveyed to a tank. The overflow from this tank escapes and disappears down an adjoining fissure in the ground. To determine whether a connection existed between this fissure (three-quarters of a mile away from the well) at Herrington Hill farm and the water-bearing strata supplying the "staple" well, I suggested that common salt should be dissolved and thrown down the fissure. Instructions were given to this effect, and two tons of salt were accordingly thrown down on May 11. . . . From May 24 a series of daily testings of the relative amounts of chlorine in the water of the reservoir and of the "feeder" was made. The chlorine in the water of the reservoir varied from 2·30 to 2·8 grains per gallon, that in the "feeder" from 4 to 6 grains per gallon. On May 29, with a view to placing beyond doubt whether the increase of chlorine thus shown was due to the salt thrown down the crevice at Herrington Hill, 5 tons of salt were washed down the crevice with a hose-pipe running for 12 hours, during which time it was estimated that some 100 tons of water were discharged. On the following day the chlorine present in the water of the " feeder " rose to 15 grains per gallon. The testing was continued for a few days longer, and on June 5 the chlorine reached the maximum amount of 24 grains per gallon. During the next few days it fell again to the former amount. The connection between the two localities was thus conclusively established, and the source of excremental contamination of the water supply demonstrated.'

A solution of lithium chloride may be used instead of common salt, inasmuch as salts of this metal are rarely if ever found in ordinary well waters, and when present even in very minute quantities can be detected in the saline residue, left on evaporation of the water, by spectroscopic analysis. The salt is quite harmless, but the expense is considerable when a large quantity has to be used. The crude sulphate, however, is comparatively cheap and as useful as the purer salts. In certain cases it has an advantage over fluorescin since it does not discolour the water and cause alarm among the users. The following is an example of its utility. At a certain waterworks the water supplied to the town suddenly became turbid and some of the inhabitants affirmed that it had an unpleasant taste and smell. So much alarm was caused that I was asked to investigate. I found that the town was supplied from two deep wells which, though only 15 feet apart, were in no way connected, pumping in one not affecting the level in the other. One well was out of use, and boring was going on from the bottom. To fill in a cavity between two tubes a large quantity of liquid cement had been poured down. Although two tons had been used, the cavity remained. The turbidity, &c., of the water from the other well coincided with the pouring down of this large quantity of cement. I caused a solution of lithium to be poured into the opening between the pipes, and samples of water were taken from the other well every hour. Within 12 hours the lithium could be easily detected in the well water, proving that communication had been opened up between the two wells and that the disturbance in the one was affecting the other. The test for lithium must be properly applied, otherwise its presence is easily overlooked, the presence of a quantity of other saline matter masking its reaction when the spectroscope test is applied. The tediousness of this process of identification militates against its use, and renders it more expensive than other methods.

Permanganate of potash is useless; it is so readily reduced by contact with the organic matter in the soil. Paraffin oil is very cheap and penetrates rapidly, but when it has once got into a well it is exceedingly difficult to remove all traces of it, hence its use is limited.

I prefer to use fluorescin wherever possible, since it is very soluble in water, has great colorific power, is easily identified, and a trace of it left in the well water is perfectly harmless. One gramme dissolved, with the addition of a little alkali, in a litre of water forms an intensely fluorescent solution, and one cubic centimetre of this mixed with 100 litres of water exhibits an unmistakable fluorescence when the water is viewed in a long tube as described below. One part therefore may be said to sensibly affect 100 million parts of water, or in other words one grain will impart a visible fluorescence to over 1000 gallons of water. This will give an idea of the amount to be used in any particular experiment.

It must be used with care, however, or untoward results may ensue. In a case in which I used this dye, the public water supply was distinctly coloured for three days. In another instance where fluorescin was put into a swallow hole to ascertain if it had any connection with a well from which water was derived to supply a large town, the water in the town was tinted within seven hours, and naturally caused some alarm. The colouring power is so intense that the greatest possible care has to be exercised to prevent particles of colouring matter getting on to the clothing, boots, hands, face or hair, as it is easily possible for water to become tinted if these precautions are neglected. Recently a small quantity was spilled on the floor of my laboratory in my absence, and it was taken up with a dustpan and brush. The result was that practically every vessel and utensil in the laboratory had to be cleaned. Solutions standing in uncovered flasks and cylinders became distinctly tinted, and a week later its presence was detected in some sand with which I am experimenting, and how the fluorescin had got into it I cannot understand. I have seen the whole of the water of a pond tinted by dust carried away on a boot.

Many aniline dyes possess enormous colorific power, but most of them when in a very dilute solution are decolourised by filtration through soil, and others are too expensive or too objectionable in other respects. Fluorescin is only affected in a very slight degree by filtration through earth, sand, or chalk. Very dilute solutions fade slowly when exposed to a bright light, but keep unchanged in the dark. In quantities of 10 lb. and upwards it can now be purchased at 7*s*. 6*d*. per lb., and I estimate the relative cost of the different substances used in sufficient quantity to affect one million gallons of water to be—

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| Fluorescin, 4*d*. | Common salt, 2*d*. |
| Ammonium chloride, 3*s*. 6*d*. | Lithium sulphate, 30*s*. to 40*s*. |

For use 1 lb. should be dissolved by the aid of 1 lb. of caustic soda in, say, 10 gallons of water. To detect the colouring matter in samples of water examined the following method seems the most reliable. Compare the tint of the suspected sample with that of a sample of the water collected prior to the experiment, each contained in white glass cylinders about 14 in. long and 1½ in. diameter. The two tubes should be held below a window or behind a screen with the surface of the water above the top of the screen and the sunlight falling thereon. Some dead black material placed at the bottom of the cylinder is a great advantage, and the brighter the light the better the effect. The relative positions of the eyes and of the cylinders must be adjusted to obtain the maximum effect. Using a Burgess tintometer (q. v.) and covering the white screen with a black cloth excellent results are obtained, and successive samples can be compared and the depth of tint registered. If the water is at all turbid it must be rendered perfectly bright by filtration. If it is necessary to use a Berkfeld or Pasteur filter for this purpose, the candle must be cleaned by passing through it a dilute solution of caustic soda until the filtrate is quite colourless.

Some waters possess a natural bluish or greenish tint which interferes somewhat with the reaction, and the result should not be regarded as positive unless fluorescence is unmistakable. The following account of probably the largest experiment yet made with fluorescin is taken from a paper contributed by me to the Association of Water Engineers and published in their 'Transactions' for the year 1907. It is quite possible that an endeavour was here made to discover too minute a trace. It is stated that 'on March 31 the colour was observed in a well water 1200 yards further N.N.W.' There was some little doubt about this, but three independent observers confirmed its presence in the filtered water, and one of these observers had carried out the experiment in previous years for Dr. Copeman. He declared that the colour was as distinct, if not more distinct, than he had observed in the Waterworks water in the experiment made in the previous year, and upon which result was based the assertion that the Waterworks well was affected by the County Asylum sewage. Later observations proved that the level of the water in this particular well was higher than the level of the chalk water where the fluorescin had been introduced. Hence, either four of us had made a mistake, or the water had flowed up hill or the water-level had varied in the interval between the observations. This proved to be the case in another instance which will be referred to shortly. However, I now conclude that where there is the slightest doubt the results should be regarded as negative. The quotation from the 'Proceedings of the Water Engineers' is as follows:

'In 1905, a series of cases of typhoid fever occurred at the County Asylum near Cambridge, and the Local Government Board instructed Dr. Monckton Copeman to investigate it, and more especially to report with reference to the risk of pollution of underground water supplies by the sewage of the Asylum. A detailed description of the geology of the district is given in Dr. Copeman's report. The asylum sewage was disposed of by a crude system of broad irrigation on land which consists of a thin layer of loamy soil covering the chalk. The well supplying the Asylum is about 60 feet deep and some 1200 feet to the west of the portion of the irrigation area selected for experiment, and about 2500 feet east from a well 70 feet deep which furnished the chief supply to the city of Cambridge. A hole was dug to the chalk on the irrigation area, and 0·5 kilo of fluorescin, dissolved by the aid of caustic soda, was washed into the chalk, and samples of water from pits and wells around afterwards collected for examination. The results not being conclusive a further experiment was made, using 5 lb. of fluorescin. The experiment was started at 11 A.M. on Oct. 18, and at 3 P.M. the colour appeared in a pit 200 feet N.N.E.; at 9 P.M. on the 20th, it was found in a pit 700 feet E.N.E., and at 4.30 P.M. on the 21st it was seen in a pit between the sewage plot and the pit in which it was observed the previous day. On Oct. 22 it was found in the water of the Asylum well, and on Oct. 27 in the water of the Fulborne well. It had therefore taken some 103 hours to travel about 1200 feet westward, and about 9 days to travel 2500 feet to the eastward. The wide diffusion is an interesting point, as the wells both to the east and the west were affected. At no time previously had these waters come under suspicion, and neither bacteriological nor chemical analyses apparently had ever indicated contamination. Dr. Copeman therefore adds: "It does not, of course, necessarily follow, because the fluorescin should have proved capable of detection at various points, inclusive of the Asylum well, at so great a distance in different directions, from the point at which it was introduced, that bacteria, harmful or otherwise, would be equally capable of transmission for so considerable a distance; but, nevertheless, the results of these experiments are decidedly instructive and important."

'The Asylum Committee were advised to make some arrangement for dealing with their sewage which should remove all risk of the effluent contaminating either of the sources of water, and the author was requested to report upon the best method of securing this desirable result. A study of the geology of the district had led him to infer that beyond a certain line the underground water would be travelling in a direction away from the wells, and to prove this a hole was bored on the site, and 2 lb. of fluorescin, dissolved and suitably diluted, was poured into the bore. It quickly disappeared, but though all the pits, wells, springs, &c., around were watched, no trace of the colouring matter was ever seen again. A further experiment on a larger scale was therefore decided upon, and carried out in the following manner: Two bore-holes, 30 feet deep, were made at opposite sides of the field selected. They were 110 yards apart, and both yielded water freely. A trench was cut from a point 6 yards north of the south bore to a point six yards south of the north bore. This trench was 96 yards long, 1 foot wide, and 6 inches deep. Water was pumped from the south bore at the rate of 25,000 gallons per day, but it filtered through the trench so rapidly that a pump had to be placed in the north bore. When the second pump was started, the whole of the trench could be flooded, and also a shorter trench cut at right angles and communicating with it. Pumping was kept up for three days to thoroughly saturate the ground, before the fluorescin experiment was commenced on March 8. A tub was mounted at each end of the long trench, and in each was placed 1 lb. of the dye. While pumping was continued, the solution was allowed to dribble into the water as it entered the trench. The time occupied in running in the solution was, on an average, four hours. On the 8th, 4 lbs. were put in, 4lbs. on the 9th, 2 lbs. on the 10th, and on the 12th, 1 lb. was run direct into the north bore-hole.

'The amount of dye used would have distinctly coloured 150 million gallons of water. Watch was kept at seventeen different points. At no time did any colour appear in the south bore-hole, but in the north one the water was tinted seven hours after the commencement of the experiment. No trace of colour appeared elsewhere until nine days later, when it showed in the water contained in a chalk pit 300 yards N.N.W.; on March 31 the colour was observed in a well water 1200 yards further N.N.W.;

and on April 7 it was detected in the marsh water near the river Cam, something like 3000 yards away, still in the same direction. At no other points has any trace of colour been detected. This second experiment, therefore, not only confirmed the first in so far as it showed that water from this locality did not travel towards either of the wells, but it also proved that the coloured water travelled in a definite direction, which, fortunately, is quite away from the sources of supply. The depth of colour observed has never been greater than that produced by 1 part of the dye in 130 million parts of water, save at the north bore-hole, where it was much more deeply tinted.'

Well waters have on many occasions been found to be impregnated with coal gas which has escaped from defective mains. Such an occurrence is detected by the odour and a search should be made for the gas main in order to localise the defect. The odour is very persistent, and if all the affected soil cannot be removed the well will probably have to be abandoned. As the soil around gasworks and mains almost invariably becomes saturated with coal gas, the proximity of such works and mains should be avoided as far as possible in selecting a site for a well.

Much of what has been said with reference to wells applies equally to springs. Superficial springs are fed by subsoil water, and can only be polluted on the gathering ground of the subsoil water, at points near or above the level of the springs. Attention, therefore, should be chiefly directed to the character of the surroundings of the springs on the upper side.

The following account of the examination of a spring water supply presents so many interesting points that a somewhat detailed description should be of general interest. The works are situated just outside the Borough of Chelmsford and supply a population of about 5000. Water is derived from a spring and from a deep well. During the greater part of the year the spring yields sufficient water to supply the whole population, but in dry seasons when the yield of the spring falls off and the demand for water is increasing the supply has to be supplemented from the deep well. In order to keep the deep well water in good condition and to be

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certain that all the pumps, machinery, &c., connected therewith are in good order, the deep well is drawn upon for a few hours each week. Analyses of the spring water are made periodically; and it was found that within twenty-four to thirty-six hours of a heavy rainfall the bacterial contents increased largely, and that the B. Coli could be detected in from 5 to 20 c.c. of the water. The water, after cessation of the rain, improved rapidly, sometimes regaining its pristine purity in two or three days. It was decided therefore to endeavour to ascertain the cause, and observations and experiments extending over six months were necessary to clear up the mystery.

The appended plan and section shows the position of the spring, the configuration of the district and the geological details necessary to understand the results of the experiments.

In 1906 house refuse was being tipped in the gravel pit to the S.E., and it was thought that it might possibly affect the quality of the spring water. Gravel is taken out to the water level and, so far as I can learn, the clay bed shown in the section *a-b* has never been reached. Observations of the water-level in the gravel pits did not indicate any rise or fall or any effect due to the pumping at the waterworks. Fluorescin put into the small ponds remained the whole winter. The water appeared to be perfectly stagnant. On Dec. 12, 1906, the workmen made a hole some feet in depth and 4 lb. of ammonium chloride was put in. Samples of spring water were collected daily and the amount of free ammonia estimated. On Dec. 26 a slight excess of ammonia was found in the spring water, and again on Jan. 14. Save on the two days named the ammonia remained normal throughout the period of observation (Dec. 12 to Jan. 18).

There were heavy rains from Dec. 13–16 and melting snow and heavy rains on Dec. 31, Jan 1 and 2, and in each case the increase of ammonia appeared about fourteen days afterwards. The increase of ammonia was so small that the results were doubtful, but further experiments were rendered unnecessary as tipping of house refuse ceased. In 1910, after discovering the effect of heavy rainfall upon the bacterial contents of the water, an attempt was made to ascertain if there was any connection between the gravel pits and the spring by introducing a quantity of fluorescin solution into a hole dug as deep as the influx of the water would allow. The water proved to be stagnant, the colour remained in the water in the hole, it did not appear in the ponds around, nor is there any reason to believe that any ever reached the well. A month was allowed to elapse before any other experiment with this colouring matter was made.

The sewers and drains between the gravel pits and the springs were tested with water and some of them found very defective. The Baddow Road sewer between the points '*c*' and '*d*' was treated in two sections, each being filled with a strong fluorescin solution and kept charged with water from an adjacent hydrant. The fluorescin solution made its appearance on the roadside beyond '*d*' and was visible for days, but no colour ever appeared in the spring water. The defective drains were similarly tested, at intervals sufficiently long to prevent any confusion arising should the spring water be affected, and besides filling the drains, trenches were cut deeper than the drains and filled with fluorescin solution. The colour remained in the trenches. No trace of colour ever appeared in the spring water. It began to be obvious that there must be a protecting bed of clay and that any contamination must arise very near the spring.

Trial bores were then made at points marked 1, 2, 3 and 4 on the plan. No. 5 represents the bore of the deep well. No boring was made to the east because the superficial gravel had been removed and lay exposed. The sections obtained were as under:

| | No. 1. | No. 2. | No. 3. | No. 4. | No. 5. |
|---|---|---|---|---|---|
| Height of ground surface above the bottom of the reservoir in which spring water rises . . . | 6·6 | 9·6 | 11·3 | 16·0 | 11·0 |
| Surface soil and gravel . . . | 3·0 | 3·6 | 0·3 | 8·6 | 2·0 |
| Clay . . . . . . | 2·3 | 4·6 | 10·0 | | |
| Gravel . . . . . . | 2·9 | 1·0 | 2·0 | 9·6 | 10·0 |
| Depth of bore . . . . | 8·0 | 9·0 | 12·3 | 18·0 | 12·0 |

In the first instance the borings were suspended as soon as clay was reached, and water only rose in Nos. 1, 2, and 4. Each of the four bores, however, was filled, at suitable intervals, with chloride of ammonium solution and water poured in from time to time to replace the little which escaped. The spring water was examined daily without any increase in the ammonia being detected. About a week was allowed to elapse between each experiment. Ammonia salts having failed, the introduction of fluorescin solution was risked, the only result being that after filling No. 1 boring, the colouring matter was found next day oozing through the top of the bank of the ditch above the level of the outlet of the reservoir. Each boring was now deepened in succession so that the lining pipe was well in the deeper gravel. In bores 3 and 4 the water-level was about the same as in the overflow from the collecting reservoir, but the level remained entirely unaffected by pumping operations, and when the reservoir was kept nearly empty for days the level in the bores did not fall. The colouring matter remained in the tubes, and, when water was poured in, the level fell very slowly and no colouring matter appeared in the spring water. This naturally caused no great surprise, but all our endeavours to get colouring matter through failed entirely. No. 5 being the bore-hole of the deep well could not be experimented with. Very different results were obtained when bores 2 and 1 were deepened. In both these the water-level rose and fell with the pumping operations, the effect being more marked in No. 2 than in No. 1. Fluorescin was placed in No. 1 and speedily appeared in the bottom of the ditch, rising up through the gravel for a distance of some yards, but it did not enter the reservoir although the water-level was kept at its lowest for days. The water-level in this bore and in No. 2 never reached the height of that of the overflow of the reservoir. When the reservoir was allowed to overflow the water-level in these bores remained 12 to 14 inches lower, but when the reservoir was kept nearly empty the water-level in the bores fell about 2 to 3 feet and remained some feet higher than the bottom of the reservoir. Finally, fluorescin was put into bore No. 2 and within twenty-four hours the spring water was tinted, and to such an extent that this source of supply had to be instantly cut off and run to waste, and the deep well utilised for supplying the town. The water remained coloured for three days, but on the fourth day it disappeared and the water was again utilised. While the reservoir was empty and the water running to waste it was carefully examined. The coloured water could be seen 'boiling' up through running sand at the N.W. corner, and flowing in a large stream under the N.W. portion of the wall. All the water which could be seen entering the reservoir was coloured and all appeared to enter at the N.W. corner. At the point '6' in the field to the west there was a ditch receiving liquid sewage from a stable. A quantity of fluorescin was put into this and ultimately a little was detected on the surface of the field lower down at '7.' It never reached the spring water, not even when heavy rains some months later washed the contents of the ditch over the ground surface between '6' and '7.'

The tests made proved—

1. That the spring water entering the reservoir must come in between the bores '5' and '2.'
2. That when the water-level is depressed in the reservoir below that in bore-hole '2,' water also enters from the direction of '2.'
3. That even during heavy continued pumping water from '1' did not flow back to the spring but continued its course northward to the outcrop in the bottom of the ditch.
4. That it was necessary to acquire the field to the west to protect the spring.

Control of this field has been secured and no manure has been placed upon it during the last twelve months, and during a period of heavy rainfall the water has remained unaffected.

The whole of the mystery is not elucidated by this research, for the exact point at which the spring water became contaminated has not been discovered, but for practical purposes the evidence obtained suffices to show that the water comes from beneath a bed of clay sufficiently thick and extensive to prevent any contamination from the sewers and drains of the houses above. The only danger to the springs arises from the manuring of the field to the west. When pumping is continued until the reservoir is nearly empty, as is done daily, there is a period of flow of water from this field to the spring, hence the necessity for obtaining control over the field.

Another cogent reason for obtaining control of the field is to prevent anyone erecting works upon it and depriving the authority of a portion of the water.

The water supplying ascending springs often travels long distances in fissures in the rocks, and is sometimes exceedingly difficult to trace. In Derbyshire and South Wales small streams are often found to disappear down 'shaks' or crevices in the limestone, and attempts to discover where the water ultimately emerges, by throwing down salt or flour, generally end in failure. These limestone beds often contain large subterranean caverns which act as reservoirs of water, and the material inserted in the fissures becomes too highly diluted ever to be discovered. Suspended matters doubtless have time to settle. On occasions, however, such underground streams have been traced by aid of soluble salts. The source of the water feeding the springs at Lausen in Switzerland, which caused an outbreak of typhoid fever, was traced by the use of common salt. Flour had been thrown down the suspected fissure on the opposite side of the hill, but failed to make its appearance in the spring water. When salt was employed the chlorine in the water markedly increased.

The following is a rather curious experience, in which by the use of common salt I traced the source of contamination of such a spring, after having failed with fluorescin.

The spring in question yields an enormous volume of water, and for years has supplied a town of some importance. Chemical analyses, made from time to time, had always given satisfactory results. When a bacteriological examination was made, the bacillus coli communis was found, and the Water Company were apprised of the fact. I was consulted, and samples were examined in my laboratory. At first the B. coli communis only was found, but at a later date the B. enteritidis sporogenes was also detected. I visited the spring, which issued from crevices in the mountain limestone, examined the country for miles round, and came to the conclusion that the pollution must be coming from a certain direction, and most probably from a point near the bend of the river where water might enter through fissures, and flow towards the spring. The river water contained both organisms, and the little soil covering the rocks where the suspicious fissures occurred simply swarmed with them. A strong alkaline solution of fluorescin was allowed to flow for twenty-four hours into the water over the fissure. This was speedily carried away, but no trace of it appeared in the spring water. I next caused half a ton of salt to be placed in the fissure, and a sample of water to be collected every three hours from the spring. The chlorine in the water increased within the twenty-four hours, and speedily fell to the normal after the whole of the salt had been dissolved. There could be no doubt that the organisms found in the spring water came from the river at the point examined, which was over a quarter of a mile from the spring.

The next example is one of success in tracing the source of pollution of a spring water without the use of chemicals, the proof of the correctness of my views being the results obtained when my report was acted upon.

The affected spring was grossly polluted, the bacterial examination showing the presence of the bacillus coli and the bacillus enteritidis sporogenes, and the chemical analyses clearly indicating contamination with sewage. As there were no houses near, the possibility of sewage pollution was scouted. The spring arose through a fissure in the limestone close to the bank of the river Derwent in Derbyshire. Upon examining the river, I found that between two points about half a mile above the spring the volume of water in the stream decreased considerably. The stream was polluted by the effluent from a sewage works about half a mile farther up the valley. This decrease could only be due to some of the water disappearing through a fissure, and from an inspection of the area I concluded that there was a connection between this fissure and the spring. The bed of the stream was then concreted, and a very short time afterwards the spring water improved in character and became satisfactory both from the chemical and bacteriological point of view.

Quite recently I had to examine a very large spring supplying a town in South Wales. The water became quite turbid after every rainfall. It was known that swallow holes abounded in one of the two valleys, just below the junction of which the spring emerged from a fissure. One valley was in the millstone grit and the other in mountain limestone. A stream flowed through each valley and they met at a point very near the spring. Upon tracing up the millstone grit stream nothing unusual was observed, but upon following up the other stream a portion of the bed was found practically dry. A few yards beyond water was again found, water which received all the sewage matter from a small mining village. I collected a sample of the water from the stream just above the point at which it disappeared, another lower down near its junction with the stream from the millstone grit valley, a third sample from the brook flowing through this valley, and a fourth from the spring furnishing the water supply to the town lower down. The analyses of these showed that the waters from the two valleys were certainly different in character, and that the spring water was practically identical with that from above the swallow holes near the mining village, and closely resembling that from lower down the same stream. I concluded, therefore, that except in periods of flood all the water in the one valley disappeared at the point indicated into fissures, that a portion of it returned to the stream lower down, and the other portion came out at the spring. Further observations proved that this surmise was correct.

I recently had to examine a public supply derived from a subsoil spring which, in dry weather, yielded water very copiously. The water gave most satisfactory results both upon chemical and bacteriological analysis. After heavy rains, the adjoining meadows were liable to flooding, and upon such occasions the water became turbid and remained so for days. The chemical analysis then showed some deterioration in the quality of the water, and a marked increase in the nitrates. The bacteriological examination revealed the presence of organisms which could only have been derived from sewage or manure. Upon examining the neighbourhood above the spring in the direction from which the subsoil water was travelling, I found about 300 yards away quite an area of highly manured market gardens. The whole phenomenon was now explicable. The heavy rains and flooding of the land washed the manurial matter, with its associated microbes, and the products of its oxidation (nitrates), into and through the subsoil at a faster rate than purification could be effected, and the polluted water finding its way along a line of little resistance passed on without undergoing further change to the spring. Obviously such a source of supply is fraught with danger, a danger the greater on account of the feeling of security likely to be engendered by repeated reports as to the excellent results obtained upon analysis.

The way in which polluted matter, containing bacteria, may under certain circumstances travel a considerable distance even in the subsoil is shown by the following experiment. A trough, 3 feet deep, 1 foot wide, and 24 feet long, was prepared and the bottom covered with small shingle and sand to the depth of one or two inches. The trough was then filled up with fine sand packed tightly. Into a cavity in the sand at one end water was poured until the whole of the sand was saturated. A tap at the opposite end was then turned so that the water drained slowly away. More water, to which an emulsion of a growth of the bacillus prodigiosus had been added, was poured into the cavity, and samples of the water trickling from the opposite end of the trough were collected every three hours. Within twenty-four hours the bacillus prodigiosus was found in this water. As it was not found in the water taken from the sand at various points, it must have travelled along with the water through the shingle and sand below, which obviously had not become so compact as to act as an efficient filter.

The use of aniline dyes and of common salt or other chemicals in solution is, however, limited, since if poured upon the ground surface they must, sooner or later, be carried down into the ground water, and if used in sufficient quantity be discoverable therein. On the other hand, if not used in sufficient quantity they may become so diluted as to escape detection, in either case leading to erroneous conclusions. The *materies morbi* of water-borne diseases is not matter in solution but organisms in suspension, and the former may reach a water supply whilst the latter are held back by the efficiency of the natural filtration. Many experiments, therefore, have been made to avoid this source of error by using such substances as flour, finely ground mineral colouring matters, &c., suspended in water, but the results generally have been unsatisfactory. Calcined magnesia I find gives the best results, being removable with difficulty, but bacteria may penetrate soil capable of keeping back even so finely divided a substance as this.

The most generally useful bacillus for experimental purposes is, probably, the bacillus prodigiosus, as it admits of very easy identification, is capable of surviving in the struggle for existence amongst earth bacteria, is very rarely found in any water supply and is destitute of any pathogenic property. It must be remembered that it is an undesirable organism to have in a house, and that if premises become infected by it there may be considerable difficulty experienced in getting rid of it. During a recent summer I was consulted by the proprietor of an hotel, who complained that all food stored in his larders became covered with a bright red slimy material in the course of twenty-four to thirty-six hours. I found the red material consisted of masses of bacillus prodigiosus. Bakeries sometimes become infected by it. A little care therefore is necessary in its use, and I should hesitate about infecting a town supply of water with the organism. This has, however, recently been done at Turin, where Abba has been experimenting on the collecting area from which the water in the subsoil is abstracted for supplying the city. Emulsions of the bacillus spread upon the ground over and near the subsoil drains collecting the water infected the water in from two to seven hours when the ground was kept flooded with water. When the ground was not artificially irrigated and the cultures were spread on the soil immediately above the collecting drains, which were laid at a depth of 9 feet, a rainfall of 1½ inches in twenty-four hours failed to infect the water in two days, but the organism made its appearance in samples of tap water taken in the city a month afterwards. It had rained on the eighteen previous days. Abba concluded from his experiments that under ordinary circumstances the bacillus prodigiosus would not pass into the water supply, but that heavy and persistent rains would carry it down into the subsoil water. He affirms that this affords valuable indications of the influence of heavy rainfalls in washing any contaminating organisms that may be present on such a gathering ground into the water supply. He found the bacillus prodigiosus a more delicate test for this purpose than the aniline colours. The following is the mode of procedure followed by Abba, Orlandi, and Rondelli at Turin. An agar culture of the bacillus was suspended in 7 or 8 cubic centimeters of sterile water, and a few drops of the emulsion poured into each of a number of Petri dishes, in which 10 c.c. of nutrient gelatine had been placed. After incubation at 22° C. for twenty-four hours the gelatine was deep red in colour and quite liquefied, but growth was allowed to continue for forty-eight hours, when the mixture was washed into flasks. Trenches were cut in the soil, and the contents of one or more flasks mixed with a considerable volume of water were poured in, or a small embankment of clay was constructed round the experimental area and the dilute emulsion poured on the ground enclosed. Water was then used for keeping the trench or enclosed area flooded for several hours. The water from the source under examination was sampled every hour, and 100 c.c. of each sample converted into broth by the addition of a sterilised solution of extract of meat was kept incubated for twenty-four hours at 20° to 22° C. At the end of this time a little of the turbid broth was poured over the surface of sterile potatoes, and the latter incubated at the above-mentioned temperature. Where the bacillus sought for was present, the surface of the potato acquired a characteristic red colour. A detailed account of Abba's experiments will be found in the 'Zeitschrift für Hygiene und Infektions-Krankheiten,' vol. xxxi. (1899), p. 66, and an abstract by Prof. E. J. McWeeney in the *Journal of State Medicine* (January 1900), p. 47.

Small springs utilised for the supply of water to but one or a few houses are often found totally unprotected, and many so-called springs are really subsoil drains sometimes draining highly manured land. Such springs cannot be considered satisfactory sources of supply.

It is much to be regretted that sanitary authorities do not possess the power to make bye-laws with reference to the protection of springs and wells, but if they would insist upon springs being properly protected and upon wells being properly constructed before granting water certificates to new houses some improvement would gradually be effected. At my suggestion the Chelmsford Rural District Council issued the following memorandum for the guidance of builders and others, and it has proved so useful that other authorities have followed their example.

### 'THE RURAL DISTRICT COUNCIL OF CHELMSFORD

### '*The Construction of Shallow Wells*

'In the large majority of cases where shallow wells yield polluted water it is due to defects in the construction of the wells. The following suggestions are submitted by the Chelmsford Rural District Council, upon the advice of their Officers, for the construction of such wells. The water which enters a well at a depth of 6 to 12 feet, depending upon the porosity of the soil, is usually efficiently filtered and purified. Water entering at a less depth is nearly always liable to be imperfectly purified and unsatisfactory in quality. The nearer the ground surface at which water can enter the greater the danger of pollution.

'It follows therefore that the upper 6 to 12 feet of the well should be water-tight, and that the top should be so finished off that no surface water can possibly gain access. It is also very desirable that the top of the well should be brought up

6 to 12 inches above the ground surface and covered with a proper flag stone or wood or iron cover.

### ‘ CONSTRUCTION OF SHALLOW WELLS

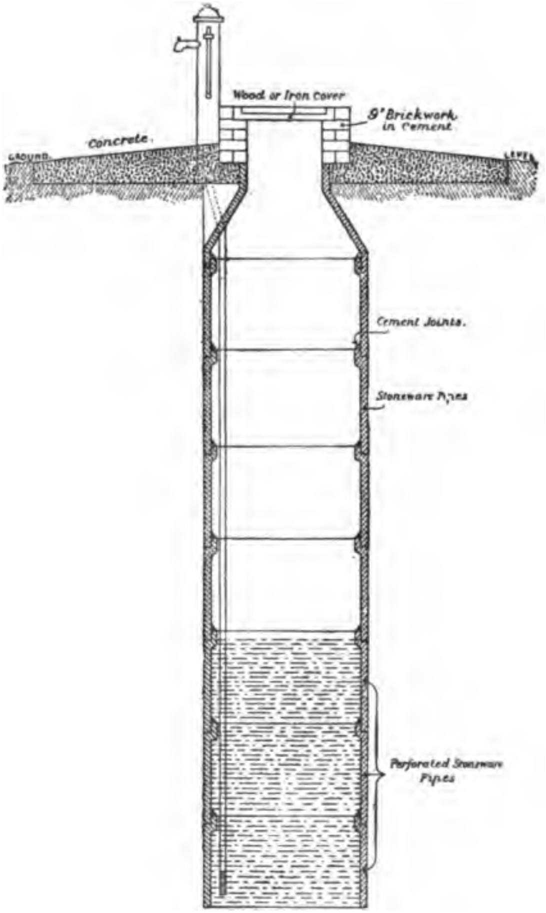

FIG. 1

‘ Plans showing two of the simplest methods of well construction are appended.

‘ As no new house can be occupied without a certificate from the Sanitary Authority to the effect that the house has a sufficient supply of wholesome water, it is important that builders and others should pay particular attention to the above suggestions, and so avoid the risk of a certificate being refused.'

However satisfactory the results of the examination of the surroundings of a spring or well supply, frequent chemical and bacteriological analyses of the water should be made, and samples should be taken under varying conditions, and especially during seasons of drought and after heavy rainfalls. It is to the neglect

'CONSTRUCTION OF SHALLOW WELLS'

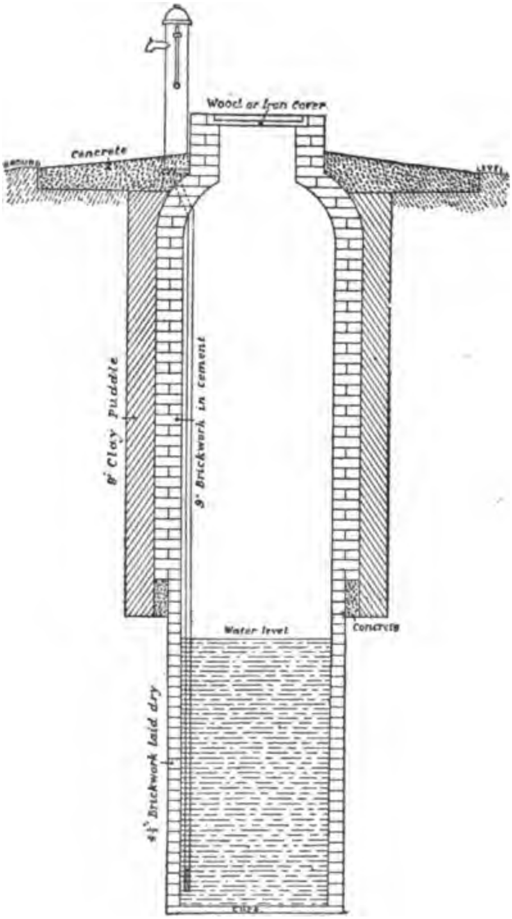

FIG. 2

of this precaution, generally found to be associated with laxity in supervision, that many outbreaks of disease have been attributed. Whilst Urban Authorities are responsible for seeing that their public water supplies are maintained 'pure and wholesome,' special powers have been given to Rural Authorities to pay all reasonable costs and expenses which must necessarily be incurred to ascertain the condition of the numerous water supplies within their districts.

It has already been remarked that no new house should be inhabited unless it has a satisfactory water supply. Rural Authorities rarely give as much attention to this subject as it deserves. They should refuse to give a certificate for habitation unless the Inspector has satisfied himself by actual inspection that the source of the water is a satisfactory one, and the Medical Officer of Health has certified that the water is wholesome and suitable for the purposes of a domestic supply.

# CHAPTER III

## EXAMINATION OF THE SOURCES OF SURFACE WATER SUPPLIES

Before expressing an opinion upon a surface water supply it is necessary (*a*) to make a thorough examination of the gathering ground, (*b*) to examine the surroundings of the storage reservoirs, and (*c*) to determine the efficiency of the filtration.

No collecting area can be considered entirely satisfactory unless the Water Authority is either the actual owner, or has in some way acquired complete sanitary control over the whole of it. Its extent can usually be ascertained from a study of the Ordnance maps, but the nature of the surface, &c., can only be learnt by actual inspection. The safest collecting area is doubtless that upon which there are the fewest inhabitants, the minimum amount of land under cultivation, the smallest number of works of any kind, and the fewest roads and footpaths. In this country there are few upland surfaces reasonably free from the possibility of pollution, and in many cases it is absolutely impossible for the Water Authority to obtain complete control of the watershed. The whole area should be examined, and every stream or rivulet traced from where it enters the storage reservoir to its source. The drainage arrangements of every farm, house, and cottage should be investigated to discover what ultimately becomes of the sewage, whether it pollutes the nearest water-course, or is carried by some sewer beyond the boundary of the collecting area. The land under cultivation should be visited to ascertain whether manure is used or sewage applied, and more especially if house refuse or the contents of pail closets or of privy cesspits are used for manurial purposes. This investigation may be supplemented by chemical and bacteriological examination of samples of water taken from the various feeders both in dry and in wet weather. Prof. Sheridan Delepine lays considerable stress on the importance of bacteriological examinations. As there is no general standard of purity he selects feeders which are uncontaminated, examines the water bacteriologically, and takes the results as a 'natural standard.' 'To find such feeders,' he says, 'the bacteriologist of course inspects the gathering ground himself, and after noting the configuration and nature of the ground, the course of the feeder, its relation to the slope which it drains, the absence or presence of cultivated areas, of paths, of houses, the possibilities of human traffic, the presence of cattle or sheep, he can then determine whether the feeder inspected is likely to be contaminated or not. . . . It is necessarily free from any bacteria associated with decomposing organic matter, human or animal diseases (providing no carcase of a dead animal is found in its neighbourhood). Such a water should be good, provided no abnormal chemical constituents are present. Even under these conditions water is liable to variations, according to the state of the weather; during heavy rains it becomes mixed with surface soil and decayed vegetable matter, washed down from the surrounding slopes or carried away from the banks of the brook itself. Consequently, during and after stormy weather, even the water of a pure feeder contains a much larger number of bacteria than it would contain when the weather is fine and the stream is running smoothly. This increase of bacteria, which is not excessive when the surface soil is of a suitable nature, does not render the water dangerous to health. Knowing the number and the kind of bacteria normally present in two or three uncontaminated feeders both during fine and rainy weather, one would therefore have standards by which to test the water collected on any other parts of the gathering ground, or taken from reservoirs within the limits of the same supply.'[1]

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[1] *Journal of State Medicine*, vol. vi. pp. 145, 193, 241, 289.

By this method Professor Delepine has traced sources of pollution which had been overlooked by the persons who inspected the watersheds. One cannot help thinking, however, that had a fraction of the time spent on the bacteriological examinations been devoted by a competent person to examining the collecting areas, the pollution would have been discovered. Yet as a supplement to such a thorough examination of the various sources of the water, the bacteriological examinations are most important. If the bacteriological results are satisfactory and confirm the results of inspection, the evidence in favour of the safety of the water is probably as conclusive as it can be made. If, on the other hand, the bacteriological examination indicates contamination of some feeder, a further inspection must be made to ascertain if any source of pollution has been overlooked. A concealed drain may be discovered, or a dead animal may be found undergoing putrefaction in the stream.

Chemical analyses are of little use in such investigations, still the survey would not be complete without analyses of each of the main feeders. Surface water usually contains a very perceptible trace of vegetable matter, and may, in fact, be more or less discoloured by peat, and in such waters a small amount of sewage is tolerably certain to be overlooked, even upon the most careful chemical analysis.

Moorland gathering grounds require special examination, to ascertain the extent of the area covered with peat and the presence of peat bogs. Peat occurs chiefly on the igneous and oldest rocks, the Cambrian, Silurian, and Devonian formations, and on the rocks of the coal measures. Water which has been in contact with peat becomes acid, the acid apparently being produced by the agency of bacteria, and the longer it remains in the peat the more acid it becomes. Such waters possess the power of dissolving lead, the plumbo-solvent power depending chiefly upon the amount of acid present. It may be found possible to cut off limited areas furnishing such acid waters, or springs may be detected yielding water containing sufficient carbonates to neutralise the acids in the peaty water. By examining the streams draining different portions of the collecting area, information will be gained as to the character of the water from each portion. Although in dry weather such water may be neutral in reaction and have little or no action upon lead, the spring water gaining access neutralising the acid in the surface water, yet in rainy weather the same streams may yield waters with a markedly acid reaction, due to the preponderance of surface water from peaty ground. As the dry weather flow will be comparatively small, the bulk of the water collected in reservoirs will be acid. Heavy storms wash out of the peat bogs water which has long been in contact with the peat, and which has a strongly acid reaction. Dr. Houston recommended in the case of proposed new waterworks, in which moorland water is to be collected, 'a careful survey of the physical characters of the gathering ground, as well as the ascertaining of the proportion of spring water to surface water at different times of the year and under different conditions of rainfall, and the testing of the quality of the spring water and its power of neutralising acid, and the quality of the surface water, especially during wet weather and sudden storms following a period of drought.'

On areas already utilised and yielding acid waters, there is no doubt that in many cases the quality of the water could be improved by 'cutting out' special areas, and arranging to 'waste' the extremely acid waters, which would otherwise enter the reservoirs at the commencement of heavy storms. When the collection of an acid water cannot be avoided, arrangements should be made for filtering through some material capable of completely neutralising the acid or of adding automatically a suitable proportion of precipitated chalk, such as is produced in the process of softening water by the addition of lime, as without some such arrangement the consumers of the water run the risk of lead poisoning if the water is conveyed from the mains to the houses through lead pipes, as is almost universally the case in Lancashire and Yorkshire, where these acid waters abound.

In examining surface water supplies, the position of the storage reservoirs and the condition of their immediate surroundings require special attention. The land nearest reservoirs, as on the banks of feeders, should not be cultivated, and it should be so protected by fencing as to prevent cattle gaining access. There are collecting areas in this country on which exist villages with churches and burial-grounds, and I have seen a public elementary school within a few yards of a reservoir, into which the sewage from the schools indirectly discharged. If reservoirs in such positions must continue to be used, there should be an efficient system of sewers to carry the sewage from the village outside the collecting area, and subsoil drains to convey the subsoil water from the churchyards into the sewers.

Cases also are on record of house refuse and the contents of pail closets being used as manure on land abutting on reservoirs, and of paper and dust therefrom, being blown about by the wind in dry weather, and floating on the surface of the water.

Footpaths or highways along the banks of reservoirs are objectionable, permitting of many forms of pollution, wilful or accidental. The shallower parts of the reservoir may be liable to become exposed during dry seasons, in which case the growth of low forms of vegetable life is encouraged and may result in the whole water supply being infected. If the ground around, sloping to the reservoir, cannot be kept absolutely free from manurial matter, it should be drained so that neither surface nor subsoil water, from portions so treated, can gain access to the reservoir.

Where a natural lake has been converted into a storage reservoir, it may be found that boats ply for hire thereon, or there may be a regular service of steamers, as on Loch Katrine. If such is the case the boats should be under the control of the authority and stringent regulations enforced to prevent pollution. Reeds, rushes, &c., often grow at the edges or in the shallow parts of such lakes, and when these decay the water may become discoloured and charged with organic matter. The possibility of anything of this kind occurring should be borne in mind when making an inspection.

Bye-passes should be provided to carry away very turbid storm waters, and the reservoirs should be sufficiently large to tide over the longest drought; otherwise in prolonged dry weather, when the water in the reservoir gets low, vegetable growths may occur and injuriously affect the character of the water. The position of the outlet should be noted; the farther this is from any inlet the better. Areas of stagnation are avoided, and there is less danger of water from any feeder passing direct to the outlet without undergoing that purification which proper and adequate storage affords (*vide* Chap. IV).

It is probable that no surface water can be considered entirely satisfactory if not carefully filtered before distribution. There may be no danger of pollution from sewage or manure, but low forms of vegetable and animal life occasionally become very prevalent, and floods may cause turbidity. Where such unfiltered waters are supplied there are constant complaints, during the summer months especially, of unsightly appearance or disagreeable odours. Organisms which are not visible at the time of delivery may multiply so rapidly afterwards, that vessels in which the water is allowed to stand for a day or two become coated with a slimy deposit, or with a distinct green growth. What is meant by efficient filtration will be described in a later chapter. Any method adapted for straining or filtering the water should therefore be carefully inspected. The wire gauze arrangements, so often used, are not sufficient to prevent the lower forms of animal and vegetable life getting into the mains. The reservoirs and the whole of the collecting area should be under constant supervision. A dead body in the reservoir or on the watershed does not improve the quality of the water.

The supply of rain-water to cottages, farms, &c., may be considered as a surface water supply, the collecting area being an artificial one instead of a natural one. Whether a roof supply is satisfactory both in quality and quantity is a question often submitted to Medical Officers of Health when certificates are applied for under Section 6, P.H. (Water) Act, 1878. There is probably no inhabited house in the British Islands the rainfall upon which is sufficient to supply the inmates with water for all domestic purposes, and I never sanction such a certificate being granted unless it is perfectly certain that no other source of supply is available. In such cases, however, if the rain-water is properly collected, and proper and sufficient provision made for its storage, the granting of certificates may be sanctioned. In other cases where the water from the public supply is very hard, the collection of rain-water is frequently resorted to, in order that it may be used for washing purposes. The methods of collection and storage are rarely satisfactory; in fact, unless the water from the roofs of buildings is passed through a 'separator' which discharges the first washings into the drains, it is bound to be polluted with bird excrement, soot, &c. An examination of the rain-water tanks should not be overlooked, as they are often in a horribly offensive condition. The water therefrom may be used for purposes of personal ablution, and I have on several occasions suspected such filthy water of having set up erysipelatoid inflammation through an abrasion of the skin. Where suitable tanks are provided, and a rain-water separator used, a very good water may be obtained from the roofs of houses in country districts. Where such tanks are placed in gardens and supplied by drains laid under the paths, there is nothing to prevent the bacillus of tetanus and other pathogenic organisms gaining access from the soil. Overflow pipes from rain-water tanks are not infrequently connected with the drains, and on more than one occasion I have found sewage backing up and entering a tank. Rain-water, however collected from the roofs of buildings, should be purified by filtration through a Pasteur or Berkefeld filter before being used for drinking purposes; but for other domestic purposes, if properly collected and stored, such filtration is unnecessary. Architects frequently provide underground filters for rain-water for the purpose of purifying it before it enters the storage tanks. I do not remember seeing a single satisfactory filter of this kind. Either the material is so coarse that little purification is effected, or so fine that it speedily becomes clogged and useless. They rarely receive any attention, and are generally found in a filthy condition.

To recapitulate, the following information should be obtained with reference to any watershed examined, from which it is purposed to derive water for domestic purposes.

1. The area of the watershed above the dam of the impounding reservoir.
2. The number and character of the streams feeding the reservoir.
3. Topography of the watershed, and the geological formations at the surface.
4. Area of boggy or peaty ground, of cultivated ground, of pasture land and woodland.
5. Population and location of villages, farms, factories, quarries, isolation hospital and other institutions, &c.
6. Method of disposal of sewage, slop water and storm water.
7. Total number of dwelling-houses, farms, &c.
8. Number of sink drains, cesspools, and privies, the contents of which may directly or indirectly reach the reservoir or the streams feeding the reservoir.
9. Number of farmyards, stables, cowsheds and pigstyes, the drainage from which may directly or indirectly reach the reservoir.
10. Picnic grounds or places of public resort (rifle ranges, &c.) on the watershed, and their location.
11. Cemeteries on the watershed, with location, size, frequencies of use, &c. If drained, what becomes of the subsoil water?
12. Public roads, location of, points of discharge of road drains.
13. Cattle drinking places.
14. Size of reservoirs, position of outlet with reference to inlets. Number of days supply of water is capable of being stored.
15. Arrangements for passing flood water or for cutting out possible sources of pollution.

The importance of some of these points will be minimised if the water is to be submitted to careful slow sand filtration before being delivered to the consumers, but not one of them should be overlooked even if filtration is to be adopted.

# CHAPTER IV

## EXAMINATION OF RIVERS AND STREAMS

Rivers and streams are fed by surface, subsoil, and spring waters; hence the complete inspection of a river would involve the examination, practically, of the whole watershed above the intake, covering an area, in some cases, of hundreds of square miles. There may be a very large population on the watershed residing in towns and villages, besides scattered houses, farms, manufactories, mines, &c., all draining directly or indirectly into the river, and there may be a floating population on the river itself. A certain portion, or possibly nearly all the land, may be under cultivation, and more or less highly manured. In such cases pollution is inevitable, and many sanitarians hold that water from such a stream cannot under any circumstances be a satisfactory source of supply. Those who are interested in this subject should study carefully the evidence given before the Royal Commission appointed to inquire into the water supply of the Metropolis, and also their report published in 1893. Here the rivers Thames and Lea were under consideration, the former with a population of over one million persons in the valley above the intake of the water companies and the latter with a population of about two hundred thousand. The pollution of the rivers is admitted, as is also the fact that some of the infective substances given off by persons suffering from zymotic diseases may and do find their way into the rivers. The following quotation gives briefly the opinions of the Commissioners and the reasons upon which they based their conclusions:

'That the amount of such (infective) substances that thus enter the Thames and the Lea is extremely small, and indeed infinitesimal in proportion to the enormous bulk of water with which it is then mixed, that there are, moreover, numerous conditions which lead to the destruction or elimination of the pathogenic bacteria during the flow down the stream, and afterwards during the sojourn of the water in the subsidence tanks and during the process of filtration: so that it is extremely doubtful, to say the least, whether a single one of these pathogenic bacteria will remain in the water as delivered to the consumer, or even in the unfiltered river water itself, that in spite of frequent examinations none have ever been detected in it, and that even on the improbable assumption that some few might exceptionally pass through the successive barriers to their entrance into the service pipes, they could not possibly be there in such number as to give rise to disease, which, according to all bacteriological researches, requires a certain quantity of such bacteria for its production.'

If the above conclusions are accepted the chief points to be attended to in investigating a river supply are:

1. The relative proportions of the polluting matter and the flow of the river when at its minimum.

2. The general character of the stream, the rate of flow, and the distance between the sources of pollution and the intake of the water.

3. The sufficiency of storage to allow of properly clarified water being distributed during periods of flood when the river water is turbid.

4. The efficiency of the subsequent storage and filtration.

The Commissioners who considered all these points in connection with the Thames and the Lea state in the final section of their report: 'We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of purity and excellence, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and Lea, because these rivers are liable to pollution, however perfect the subsequent purification either by natural or artificial means may be, but having regard to the experience of London during the last thirty years, and to the evidence given to us on the subject, we do not believe that any danger exists of the spread of disease by the use of this water, provided that there is adequate storage, and that the water is efficiently filtered before delivery to the consumers.'

As a general rule, rivers are inspected with the view of detecting sources of pollution in order to secure their removal. The stream should be carefully followed up and every tributary drain and ditch connected therewith noted, as well as the extent and character of the areas liable to flood, and the proximity of highly manured land, of sewage works, and of manufactories. Samples of all liquids being discharged therein, and of the river water at different points, should be taken and submitted to chemical and bacteriological examination. The possibility of sewers discharging under the surface, for purpose of concealment, should not be forgotten, nor should the fact that sewage may accumulate in ditches during dry seasons and the whole be washed into the river with the first heavy rainfall be overlooked. The amount of oxygen found in the water taken at different points may furnish valuable information as to the rapidity with which the process of self-purification is taking place. A report on the condition of the river Severn prepared by the late Professor Boyce for the Royal Commission on Sewage Disposal, and contained in their interim report, touches on several points connected with river examination, and is worth perusal by anyone interested in the condition of our streams. The detection of all the sources of pollution in a river of any length is a matter of very considerable difficulty. Even if the whole length of the banks on both sides is examined, some intermittent or even continuous source of contamination may be overlooked. Chemical and bacteriological examinations of the water may in such cases lead to further investigation and the discovery of the cause of pollution. Recently, when examining an Essex river, I was led to believe that between two given points some polluting matter which I had failed to discover was entering the stream. A further survey revealed the fact that the sewage from a large group of houses was conveyed to a tank in a field, and that it was supposed to be then disposed of by broad irrigation. The tenant of the land, instead of so treating the sewage, had cut a grip across the field which conveyed the raw sewage directly into the river. It entered through an opening in some dense brushwood, and could not be seen from the banks.

As the discharge of improperly treated sewage into streams is illegal, the person inspecting must have an intimate knowledge of the various processes of sewage purification, so as to be able to say whether the works are of such a character as to deal in the most effective manner with the sewage, both in dry weather and in periods of heavy rainfall. Such works also should be subject to constant and rigorous supervision. Unfortunately the most modern bacterial methods of sewage disposal fail to remove a large proportion of the bacteria in the sewage, and especially, apparently, of those belonging to the coli group. Where suitable land is available, there is no doubt an effluent of far greater bacterial purity can be obtained than has yet been effected by treatment of sewage on bacteria beds only, but I have recently examined effluents obtained from beds upon which the sewage was spread by a sprinkling arrangement which were very little inferior to those obtained by land treatment. Where barges, boats, &c., ply upon a river from which water is taken for the supply of any community, power should be obtained to make regulations for preventing pollution by the pumping out of bilge water or the casting of refuse into the stream.

The formation of Local Rivers Boards under a Central Board, as suggested by the Royal Commission on Sewage Disposal, if carried into effect, will probably result in such Boards being given greatly increased powers for the prevention of the pollution of rivers and of sources of water supply generally.

In many localities rivers are more polluted by effluents from manufactories, quarries, mines, &c., than by sewage. It should be ascertained whether there is any infringement of the Rivers Pollution Act, either by the casting in of solid refuse, or the inflow of liquid effluents. This implies a knowledge of the best practical means of purifying the waste liquors from works of the most diverse character, and, as in the case of sewage works, the exercise of constant supervision to see that the best means of purification have been adopted, and that they are properly used. The existence of bye-passes permitting untreated, or but partially treated sewage, or manufacturers' refuse, to be conveyed to the river must always be regarded with suspicion, and if possible steps should be taken to secure their removal. Every gasworks should be visited to ascertain what becomes of the spent liquors. They are often conveyed surreptitiously into the nearest stream.

But when everything possible has been done to secure the most efficient purification of such waste products, rivers receiving sewage and manufacturing effluents can never be regarded as really satisfactory sources of water supply, but as in most cases they must continue to be so used, the arrangements for collecting water, for storage, and for filtration should receive special attention. The storage reservoirs provided should be so large as to admit of a supply of purified water being maintained during periods of heavy rainfall without any water being taken from the river whilst it is in a turbid condition. It has been suggested that this storage should equal fifty-six days' supply (Balfour Commission). In any case, at the height of a flood the water, which will contain all the washings from ditches, and possibly all the sewage from the various works within the drainage area, and much of the mud from the bed of the river, should not be collected. The admission of such turbid and polluted water would defile all the water in the storage reservoirs for a considerable period.

Apart from the necessity of storage to avoid the intake of storm water, it is necessary for securing a certain amount of purification of the water by natural processes, sedimentation, insolation, and destruction of objectionable bacteria by the action of other low forms of life, &c. It is a well-known fact that the bacilli of typhoid fever do not live long in water, and that in a stored water they tend rapidly to disappear. Experiments which I have made or assisted in making in connection with the waters of various rivers prove that over 99 per cent. of the typhoid bacilli introduced into such a water disappear within one week. One week's storage therefore increases the safety of the water over a hundredfold. In fourteen days 99·9 per cent. of the bacilli disappear, hence fourteen days' storage increases the safety a thousandfold.

Dr. Houston, the Water Examiner to the Metropolitan Water Board, who has carried out on a large scale a series of investigations on the effect of storage, summarises his results as under (Third Research Report):

1. Storage reduces the number of bacteria of all sorts.
2. Storage reduces the number of bacteria capable of growing on agar at blood-heat.
3. Storage reduces the number of bacteria capable of growing in a bile salt medium at blood-heat, chiefly excremental bacteria.
4. Storage reduces the number of coli-like microbes.
5. Storage reduces the number of typical B. coli.
6. Storage alters certain bacteriological river-water ratios: for example, it reduces the number of typical B. coli to a proportionately greater extent than it reduces the number of bacteria of all sorts.
7. Storage, if sufficiently prolonged, devitalises the microbes of water-borne disease (e.g. the typhoid bacillus and cholera vibrio).
8. Storage reduces the amount of suspended matter.
9. Storage reduces the amount of colour.
10. Storage reduces the amount of ammoniacal nitrogen.
11. Storage reduces the amount of oxygen absorbed from permanganate.
12. Storage usually reduces the hardness and may reduce (or alter the quality of) the albuminoid nitrogen.
13. Storage alters certain chemical river-water ratios; for example, the colour results improve more than the results yielded by the permanganate test.

14. Storage has a marked levelling effect on the totality of water delivered to the filter beds.

15. Storage tends generally to lengthen the life of the filters. (Only under exceptional conditions is the converse true.)

16. An adequately stored water is to be regarded as a 'safe' water, and the 'safety change' which has occurred in a stored water can be recognised by appropriate tests.

17. The use of stored water enables a constant check to be maintained on the safety of London's water antecedent to, and irrespective of, filtration.

18. The use of stored water goes far to wipe out the gravity of the charge that the chief sources of London's water supply are from sewage-polluted rivers.

19. The use of adequately stored water renders any accidental breakdown in the filtering arrangements much less serious than might otherwise be the case.

20. The habitual use of stored water would lighten the grave responsibilities of the Water Board, as regards the safety of the London Water Supply, and would tend to create a sense of security amongst those who watch over the health of the Metropolis.

His final conclusion is 'That raw river-water should be stored *antecedent* to filtration, preferably for thirty days. The question whether the thirty days' storage should be fixed on a maximum or on a minimum basis, must be left unanswered; but if the former alternative be chosen the desirability of employing supplementary processes of water purification to tide over emergencies is worthy of consideration.'

In his Seventh Research Report he advocates small pre-storage settlement reservoirs, and says: 'If this pre-storage system of settlement were adopted there is no reason why, when the river water was especially unsatisfactory in quality, the good results obtained by simple sedimentation should not be considerable enhanced by the use of such coagulents as sulphate of alumina, alumino ferric, &c.'

It must be remembered that Dr. Houston is only dealing with the Metropolitan Water Supply, and his conclusions will require modification according to the circumstances obtaining in any other area of supply. When it is absolutely necessary to take water from a polluted river when in flood, there should be an arrangement for passing it through roughing filters such as Peuch's before it is allowed to enter the large storage reservoir. The dimensions of these filters, reservoirs, &c., depend upon many conditions, all of which should be noted. The more important of these conditions are, the longest period of flood, the extent to which the river is polluted, the amount of sedimentary matter which it brings down, the amount of water which has to be abstracted daily, and whether the storage is quiescent or with continuous flow. Naturally if it is possible to avoid taking in flood-water, less storage, &c., will be necessary; but it must be remembered that during such an interval the storage reservoirs are being depleted, and that there must be some arrangement for filling them again without unnecessary disturbance of the deposited matter, and without letting the incoming water travel too rapidly to the outlets.

The conclusions arrived at with reference to the length of time which impure waters should be stored are chiefly based upon experimental results on the viability of the typhoid bacillus in water. Yet it is doubtful whether this organism alone can induce the disease. I have imbibed millions of them and so has Dr. Houston, yet neither is one penny the worse. Every known fact with reference to epidemics of this fever indicates that the typhoid bacillus alone is not the cause of the disease, and it has long been suspected that some other organism, either by itself or in conjunction with the typhoid bacillus, was the cause. Quite recently a discovery has been made which may necessitate an entire reconsideration of the relation of water to typhoid fever. This discovery is thus referred to in the *Lancet* of March 23, 1912:

> A new element has entered into the etiology of typhoid fever—namely, an anaërobic bacillus. It is remarkable how much views with regard to the etiology of typhoid fever have changed during the course of the last few years, and if the importance of this new factor

is confirmed it may lead to further modifications. Loris-Melikov [1] is the author of this new discovery. He tried the experiment of planting some fæces from a typhoid patient in broth containing bile and a piece of boiled white of egg. In this a deposit formed, with some of which a glucose-agar medium was inoculated. In a few days small transparent colonies made their appearance, and these were found to consist of non-motile, Gram-positive, sporing bacilli, which are strictly anaërobic, and grow well only at a temperature of 37° C. In view of the probably large number of undescribed anaërobic bacteria which may occur in the human intestine, such a finding is not remarkable, but the sequel is distinctly interesting. By injecting cultures of this organism into various animals it was found that it has a specific action on lymphoid tissue, and in particular on Peyer's patches in the intestine, on which it exercised a distinctly necrotic action. Unmistakable swelling and ulceration were the result. This is decidedly curious, and will undoubtedly lead to further investigation. Still more curious is the fact that these bacilli were found only in fæces from typhoid patients and not in normal stools. Of equal interest is the fact that they were agglutinated by typhoid patients' serum in a dilution of as much as 1 in 100. Loris-Melikov considers that this organism has a local necrotic action, and that it adds to the septicæmic effect of the typhoid bacillus; his researches and results naturally raise the question, Is the *Bacillus typhosus* Eberth, after all, the real and only cause of typhoid fever?

Whether this new bacillus can live in water or not, and, if so, for how long and under what conditions, will have to be investigated. As it is spore-bearing, its spores may be capable of retaining their vitality for a very long period, even in water. Still, if it is incapable of causing typhoid fever save where in association with the B. typhosus, its discovery will probably not affect the question of water storage.

In Germany there are numerous men of high scientific attainments who hold that it is quite impossible for drinking water ever to disseminate typhoid fever or cholera. This is entirely contrary to experience in this country, but there is no question that many outbreaks are referred to drinking water which are due to other causes. It is only necessary for an outbreak to occur for the water to become suspected, and failure to trace the infection to any other source leads to the water being condemned, especially if there is discovered any possible, however improbable, source of contamination. There is scarcely a water supply in the country which does not stand to be condemned at some time on such evidence. Naturally an investigator does not like to acknowledge himself baffled in his endeavour to discover the cause of an outbreak of typhoid fever, and, rather than acknowledge defeat, the water supply is condemned. This can be safely done because it is practically impossible for the water authority to prove the negative.

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[1] *C. R. Soc. Biol.*, lxx. 1911, p. 865.

The fact that typhoid fever could be caused by the use of infected milk, shell-fish, water-cress, &c., and that infection could be carried by flies would have been discovered much earlier had it not been for the belief that water was practically always, if not always, the source of infection.

The freedom from typhoid outbreaks of rural communities using shallow well water of a notoriously polluted character is well known, and probably the German explanation of this fact is the true one. It is thus expressed by Prof. J. König in an article published in May, 1904, on 'Die Bedentung der chemischen und bacteriologischen Untersuchung für die Beurteilung des Wassers':

'Pathogenic bacteria in the blood of human beings and of animals have the power of multiplying rapidly, so that in a few hours one germ may produce millions, and the number of phagocytes is no longer equal to their destruction. In water, however, exactly the opposite is the case, the Infusoria are continuously multiplying, whilst the pathogenic bacteria are not capable of increasing in number. . . . In 1 c.c. of water from a well at the Hygienic Institute of Munich, 21,414,262 typhoid bacteria died off within twenty-four hours. Thus the Infusoria in one litre of water destroyed 21,414,262,000 typhoid bacilli in twenty-four hours. It is seldom that a well contains less than 20 gallons of water, and reckoning this as the minimum quantity we find that in such a well 2,141,426,100,000 typhoid bacilli would be destroyed in twenty-four hours.

'A whole typhoid stool may contain 2,000,000,000 bacteria and a thousand such stools 2,000,000,000,000 typhoid bacteria, which is fewer than the water in the well has power to destroy. Assuming that 1000 typhoid stools were daily thrown into the well of the Hygienic Institute, the next day all the typhoid bacilli would have disappeared.

'The dirtier a well, i.e. the more protozoa it contains, the greater the number of typhoid bacteria it will destroy. The destroying effect is trifling in waters which are quite pure.'

Prof. König then proceeds to argue that as the soil and all spring and well waters contain protozoa it is impossible for the typhoid bacillus to survive sufficiently long to produce an epidemic.

It is possibly true that there is greater risk incurred when a pure water becomes specifically infected than when the infection of an impure water occurs, and that it is because of the great general purity of our public water supplies that water-borne epidemics appear to occur more frequently here than in Germany. In any case we prefer our drinking water to be free from Infusoria and from all the low forms of animal life and vegetable life, hence all river water supplies should be filtered and the character of the system of filtration adopted should be inquired into after the examination of the river and watershed has been completed. The nature of this latter examination has already been referred to, and the information obtained should be summarised as in the Table at the end of Chapter III.

If slow sand filtration is adopted, the number of the beds and their size should be recorded, so that a calculation can be made as to their sufficiency under all circumstances. The storage capacity for the filtered water should be ascertained, to see that it is ample to permit of the filtration proceeding at a uniform rate whatever the fluctuations in the demand. There should be arrangements for regulating the rate of filtration and for allowing samples of filtered water being taken from the outlet of each bed. Where mechanical filters are used, their efficiency can only be ascertained by a systematic bacteriological examination of the water passing through them, and for this purpose there should be arrangements permitting samples to be obtained from each filter. Bacteria multiply rapidly in the filtering material if the filters are allowed to rest, even for a few hours, hence samples should always be collected at known intervals from the commencement of the filtration, the first sample being collected as soon as water begins to pass. This subject will be further discussed in the section relating to the biology of sand filtration and the bacteriological examination of water.

# CHAPTER V

## EXAMINATION OF SERVICE RESERVOIRS, WATER MAINS, &C.

Service reservoirs may be improperly constructed or inadequately protected. Where excavated in the ground the upper edges may not be raised above the ground level, hence frogs and other animals may get in, and heavy rainfalls may wash in objectionable matter. Recently I have had to examine two such reservoirs. In the first instance a serious and widespread outbreak of diarrhœa occurred among the users of water which passed through a service tank. There had been an exceptionally heavy fall of rain a few days before the outbreak occurred, and when the tank was examined I found a good deal of earth and sand had been washed in from the adjacent road, and from a patch of garden ground adjoining one side of the reservoir. There were also many worms and other objectionable forms of animal life at the bottom of the tank. When the reservoir was 'cut out' for cleaning and improving, the epidemic came to an abrupt termination. In the second case consumers of the water complained that the water when drawn from the taps frequently contained small worms and other visible organisms. The service tank was surrounded by a narrow footpath, and beyond this the ground was raised in the form of an embankment, the slope being covered with grass. Here again the reservoir when examined was found to contain soil, worms, &c., which had undoubtedly been washed in from the ground around. The raising of the edges of the tank well above the ground level would prevent pollution of this character.

Such reservoirs are better covered so as to prevent the access of light, rain, bird droppings, animals, insects, dust, &c. If light gains access there is danger of algoid growth manifesting itself and causing trouble, and if uncovered all kinds of objectionable matters may gain access. The overflow from such a tank should be traced. I found on one occasion an overflow pipe very improperly trapped and connected with a public sewer. Even with a proper trap this is an objectionable arrangement, as water may overflow so rarely that the evaporation of the water in the trap would cause it to be unsealed and therefore useless.

Water engineers now avoid 'dead ends' as far as possible, the mains being made to intercommunicate wherever practicable so as to ensure constant circulation. Near 'dead ends' there is always a tendency for sedimentary matter to be deposited, for bacterial and fungoid growth to develop, and for rust to form and accumulate. Frequent flushing in a great measure will prevent any annoyance being caused to the consumers of the water, but the flushing may be neglected, and if not neglected much unnecessary waste of water occurs.

New mains often give rise to complaints, the tarry matter with which the pipes are coated inside communicating a distinct odour and flavour to the water. This may continue for a few weeks, or a year or more, according to the character of the coating and the amount of water passing through the pipes. Occasionally also the water becomes discoloured from this cause. This is due to the coating either being of an unsuitable character, or not being properly applied, or to the pipes being used before the coating has firmly hardened. The last complaint of this kind into which I examined was one in which the water was quite unfit for use owing to its being discoloured and offensive in odour. I found the pipes had been imported from Belgium. Occasionally the tow used for caulking the joints of new mains affects the flavour of the water for a time. Water pipes are often deposited in ditches by the roadside until they can be laid. Here polluting matter may gain access, and if, after fixing, the mains are not thoroughly flushed for a period, the contaminating matter may be imbibed by the consumers.

Inquiries on these points should be made whenever the cause of any change in the character of a water supplied from mains is being investigated.

Where the water is very soft, and especially if derived from peaty moorlands, the action of the water on the service pipes will require attention, and more particularly if these pipes are of lead. Many waters corrode the iron mains, sometimes causing perforation, at others coating the pipes with oxide. This coating may become an incrustation, the incrustation increasing in thickness, or the iron of the main itself may become thinner, until either the main gives way or its calibre becomes so limited that the necessary quantity of water will no longer pass. When such a water is being used the mains require frequent testing and examination.

Interesting finds are often made when old water mains are examined. A short time ago some mains removed at Poplar were found to be encrusted with fresh-water molluscs, and during the present year a 36-inch main, taken up at Hampton-on-Thames, was opened and its bore was found to be reduced to 9 inches by a mass of fresh-water mussels. It is said that 90 tons of mussels were removed from a quarter mile of the main. No less than eleven species were found in the Poplar mains, but Locard discovered many more species in the water mains of Paris.

As with efficient filtration it is difficult to see how such organisms could gain access to the mains, their presence shows that the water supply has not at all times been satisfactory.

Impurities may enter water mains through defective joints, cracks, and perforations, and also at ball hydrants and air-valves. The condition of the water mains should be, as far as possible, ascertained, especially if they are old, the ground being opened out at selected places for this purpose. Where ball hydrants are in use or air-valves fixed, their position should be ascertained, since if polluting matter can gain access to them it is certain, sooner or later, to get into the mains. The danger of pollution arising from defective mains, ball hydrants, &c., is much less when the supply of water is 'constant' and under considerable pressure. Insuction is much more likely to occur if the supply is 'intermittent,' but may take place even with a constant supply if the pressure varies, or if there is a contraction just beyond the defect. Moreover, with a constant supply the water must be occasionally turned off for repairs, &c. At the point where insuction is suspected the ground should be saturated with strong fluorescin solution, and a watch kept upon the water drawn from a suitable point beyond. Occasionally a branch pipe direct from the main is connected with the manhole of a sewer, and the water used for flushing purposes. This is an objectionable arrangement, as with a defective tap, or with a tap left 'on,' sewer air may be drawn into the mains. The houses supplied by a particular main can be identified by injecting a solution of potassium permanganate into the main and then ascertaining the houses to which a tinted water is being supplied. In a house in which there are several cisterns the pipes from which cannot be directly traced, the tap connected with each can be identified by tinting the cistern waters with innocuous colouring matters such as potassium permanganate and fluorescin.

In some old towns, water-closets still exist which are flushed with water directly from the main, the 'stool' tap being fixed on the seat of the closet, the end terminating within the pan itself. Insuction of filth in such cases has been proved by plugging the trap beneath the closet and filling the pan with a solution of potassium permanganate. In one recorded case the coloured liquid was drawn into the mains, yet no trace ever appeared in the water taken therefrom. Probably the permanganate was decolourised by the rust deposited in the mains or the colour lost on account of excessive dilution. The investigation of the distributing arrangements in a house should include first an examination of the storage cisterns (if any) to ascertain if they are of objectionable material, if they are in easily accessible and suitable positions, and are clean and properly connected. Next, all the pipes communicating with the cistern should be traced, more especially to discover whether there are any direct connections with water-closets, slop-sinks, or urinals, or whether there are any overflows terminating in objectionable positions. The position of the tap or taps from which drinking-water is drawn should be ascertained, and the supply pipe traced to find whether the water comes directly from the main or from a cistern.

Comparison of the results obtained by analyses of samples of water taken directly from the main and from the tap supplying water for drinking purposes is often useful. Recently on making such analyses in connection with the water supply of a large public institution I found the supply from the main quite satisfactory, whilst that from the tap was impure. Upon examination it was found that the water passed through a cistern containing the remains of a decomposing bird. The contamination of water in house cisterns is so common an occurrence that no sample of water which has passed through a cistern should be taken as a sample of a public water supply. A few years ago a series of cases of typhoid fever occurred in a group of cottages near a sewage works and house refuse tip. The cottages swarmed with flies and the small cisterns in the sculleries each contained thousands. I have no doubt the flies carried the specific infection from the sewage sludge and house refuse to the water supply to the cottages. The water taken at the cottages was bad both chemically and bacteriologically, whilst that taken from the street main was excellent in all respects.

The extent to which a whole water supply may be affected by ball hydrants is well illustrated by the experience of Edinburgh in the winter of 1905–6 as recorded by Dr. Williamson, the Chief Sanitary Inspector of the city.

Early in December 1905 complaints were received that the water supply to the city contained water-fleas, and Dr. Williamson obtained specimens of these and found that they were not water-fleas, but insects of an entirely different character, usually known as ' springtails ' on account of the peculiar manner in which they jump about. Several different species were ultimately recognised by the authorities consulted. They are not aquatic, but breed in damp dark places, yet they were found in some of the water cisterns examined, and it was ultimately discovered that the insects were breeding in the boxes of the ball hydrants. In about 30 per cent. of the ball hydrants inspected the insects were found in larger or smaller numbers. In not a single instance were they found in the valve hydrants. Some of the ball hydrant boxes were found half full of liquid filth, but in such cases no insects were present. The way in which the insects and other objectionable matters were conveyed from the hydrant boxes to the house water supplies was ascertained in the following manner as described in Dr. Williamson's report :

'It still remained necessary, in order to complete the inquiry, to establish beyond all doubt the fact that insects found present in the ball hydrant can, with the greatest readiness, be transferred to cisterns in the immediate vicinity, and, in order to determine this, experiments were conducted.

'A hydrant box was selected, situated in Cowgate, and containing a considerable number of insects. The majority of these were found present on the under-surface of the metal cover placed over the ball valve. This cover was left *in situ*, and the cisterns in the tenements in the immediate vicinity were emptied and cleansed. Gauze bags were affixed to each feeding pipe supplying these and, with the assistance of a Water-officer, the pressure in the street main pipe was reduced. The moment this was accomplished the ball valve in the hydrant box was opened and the contents of the box were rapidly transferred to the main water pipe ; the supply to the tenements was immediately turned on and the cisterns filled. On this being completed the gauze traps were removed, and, in five out of eight of these, the insects were found present. This formed an absolutely convincing proof of the ease with which insects existing within a hydrant box, as well as all liquid material, may gain access to the main water supply, and from thence to the cisterns in the vicinity, whenever the pressure is lowered ; and it further proves that it does so readily, despite the precaution of placing a metal cover over the ball, in conformity with the system at present generally in use. This cover, in the experiment just recorded, formed no impediment to the immediate disappearance of the box contents.

'The last experiment made was with the view of determining the facility with which any liquid contents of a hydrant box could gain access to the water supply. For this purpose a box was filled with clean water, and the pressure in the main was lowered by the method commonly adopted. Within a period of three seconds the whole contents of the box were sucked into the main water pipe. This experiment was important in order to demonstrate with precision the destination of the objectionable liquid which was found present in several hydrant boxes in the city, and which must of necessity collect there from time to time.'

This Edinburgh experience emphasises the importance of including the mains and all connected therewith in an investigation bearing upon the contamination of a public water supply.

Occasionally it is necessary to cut out short lengths of main to ascertain the condition or the presence of any growth. Such growths are likely to occur where moorland water, inadequately filtered, is turned into the mains. Low forms of vegetable or animal life capable of growing in the dark and of attaching themselves to the surface of the pipes may increase to such an extent as to block the smaller mains. Recently, in an English town, when a length of main was cut out, it was found to be encrusted with a moss-like growth of Polyzoa Plumatella, a fresh-water polyp referred to in a later section. Further investigation showed that it only occurred in the newer and well-coated pipes, and not in the old and very rusty pipes. The pipe on which it was first observed had only been down two and a half years. It causes considerable trouble, growing apparently in the warm weather, then breaking away and blocking water-metres, ball-cocks, &c. It has also made its appearance in the water drawn from the mains, especially when the water has been allowed to flow, full-bore, into a bath. How it was introduced, how long it had been present when discovered, and how to get rid of it are problems to be solved. So far it has not affected the taste or smell, but there can be little doubt that were quantities of it to die and decompose it would affect the quality of the water. If the water had been filtered before it entered the mains, probably the growth would never have occurred; and if filtration were now introduced the Polyzoa would be deprived of their food supply, and in a short time would almost certainly disappear.

It is also often necessary to inquire whether the mains or service pipes are likely to be affected by electrical currents, and in house supplies faulty electric wiring may have an effect upon the water. I have met with one case in which traces of copper were found in a water, which apparently were due to the contact of an electric wire with the service pipe setting up galvanic action between the lead pipe and the brass tap. Dr. Houston, in his report to the Metropolitan Water Board for 1910–11, commenting on the complaints received during the year, gives an illustration of this danger. He says: 'One especially interesting complaint was made during the year. The complainant arrived at the laboratories with a sample of water taken from a cistern obviously containing large quantities of copper, together with a ball valve almost completely eaten away, apparently by some corrosive agent. This was alleged to be the second ball valve which had been similarly affected within the space of a few months. Acting on the suspicion that some electrical defects existed in the house in question, a telephone message was sent to the Engineering Department, and when inquiry was made this proved to be the cause of the trouble, two electric wires being in contact with a water pipe. The corrosion ceased immediately after the electric wires had been placed in a safe position.'

It is now becoming recognised that powerful underground currents affect the water mains, and on occasions no doubt the character of the water passing through the mains is also affected, a trace of the metal entering into solution. The corrosion, external or internal, may ultimately result in the destruction of the main and permit of insuction of any liquid in contact with it.

Upon occasions the chemist is called upon to explain the action of public water supplies on mains or service pipes, in which case it is necessary to make a complete analysis of the saline constituents of the water and to estimate the amount of free carbonic acid and oxygen which it contains. This is easily done, and it is probable that the action which takes place is entirely due to the presence of this acid, or to the acid plus the oxygen found dissolved in the water. In one district where a number of houses had recently been connected with mains carrying a pure chalk water, there were complaints of an oily scum forming on the water when boiled, and one user submitted a sample to an analyst. The analyst condemned it as polluted because it contained nitrites and a little ammonia, which he said pointed to sewage pollution. Upon inquiry I found that all the complaints arose at houses with long lengths of service pipes of galvanised iron, and that the condemned water contained zinc, the presence of which was overlooked by the analyst. The oily film produced on boiling was due to the iridescence of the carbonate of zinc thrown out of solution by heating, and the nitrites and ammonia were due to the reducing action of the zinc on the nitrates present in the water. The result of the investigation was that the Water Company adopted regulations insisting upon the use of lead for service pipes, and the Local Government Board after holding a public inquiry sanctioned the regulations.

In another instance a water authority extended their mains in several directions, and after the connections had been made, complaints were received from persons along the route of the extended mains about the turbidity of the water, but especially along the T—— main. A somewhat lengthy investigation was made, which showed that the water from the old mains was always bright, but that all samples taken from the three recent extensions were more or less turbid, either when drawn or within a few minutes afterwards. The worst samples were always from the T—— main, which is 2600 yards long and has no house connection for a distance of 2000 yards. The water might be merely tinted brown and be fairly clear when drawn, but upon exposure to the air it speedily began to deposit oxide of iron, and in a few hours there would be a marked brick-red sediment at the bottom of the containing vessel. The T—— branch pipe is not coated with the ordinary black varnish but with some kind of paint, but the other branches complained of are coated in the usual manner. Samples of these latter were obtained, and having plugged one end they were allowed to stand full of water for twenty-four hours. In no case did the water take up more than the most minute trace of iron and the samples remained perfectly bright afterwards. When, however, patches of the varnish inside were scraped off, the water dissolved marked quantities of iron, and became turbid afterwards when exposed to air. There can be no doubt that in these branch mains the pipes are not thoroughly coated, hence the action of the water.

The analysis of this water shows it to contain in each gallon :

| | | |
|---|---|---|
| Calcium carbonate | 3·5 | grains. |
| Calcium sulphate | 1·9 | „ |
| Magnesium sulphate | 0·7 | „ |
| Magnesium chloride | 0·6 | „ |
| Sodium chloride | 1·7 | „ |
| Sodium nitrate | 2·7 | „ |
| Silica, &c. | 0·4 | „ |
| Total | 11·5 | |

The amount of carbonate present is barely sufficient to prevent the action upon metals, especially in the presence of an excess of carbonic acid, and I found that the water acted markedly upon galvanised iron pipes. There is little doubt that this acid was dissolving iron from parts of the main imperfectly coated, and I attribute the action complained of entirely to the faulty coating of the recently laid mains.

In both the above instances investigations into the character of the water mains, service pipes, &c., were found to be absolutely necessary to supplement the information gained by the analyses of the waters, in order to enable a correct conclusion to be drawn.

# PART II

## *VARIOUS METHODS OF EXAMINING WATER AND THE INTERPRETATION OF THE RESULTS OF SUCH EXAMINATIONS*

## CHAPTER VI

### OBJECTS AND METHODS OF ANALYSIS

Confining our attention at present entirely to chemical analyses, it must be admitted that such analyses are generally made to decide whether a water from a given source is suitable for domestic purposes, and whether it can be used without the risk of conveying disease, but as such an analysis, however carefully made and however complete, can tell us little or nothing about the liability to contamination, it is obvious that it is impossible to judge from the analytical results alone whether any source will yield a water which can be used without risk ; yet I constantly see waters reported to be good and wholesome which I know are eminently unsafe, and occasionally I hear of waters being condemned which I know are wholesome and quite free from liability to pollution. By chemical methods gross pollution can be detected, but, as will be demonstrated later, slight traces of sewage cannot be detected, and larger traces may be confounded with harmless vegetable matter. By analyses, however, variation in character can be discovered, and whether the saline constituents are in quantity and quality harmless and unobjectionable or not can be determined.

Analyses may also be undertaken for comparative purposes, as in selecting a source of supply. Systematic analyses of water from a given source may be made in order to ascertain the extent of the variation in quality, the effect of excessive or deficient rainfall, the effect of continuous pumping, &c. In well-sinking or boring the various springs tapped are examined to ascertain whether they should be excluded or admitted. Sometimes analyses are made to discover the cause of some change observed in the water such as may be due to its action on iron or lead pipes, or to the insuction of subsoil water into the mains. Or a water may be specially examined to determine what action, if any, it has upon the metals of which cisterns and mains are usually composed, or the saline constituents may be determined to ascertain whether the water is suitable for particular manufacturing purposes such as brewing and dyeing, or for general boiler purposes.

Special examinations are required if the water is believed to contain certain substances conferring medicinal properties. Occasionally special attention is devoted to the analysis of the gases dissolved in the water to ascertain whether the water is fully oxygenated or whether some change is going on accompanied by the absorption of oxygen, as in determining the purifying effect of flow in a river.

In considering the suitability of a water for a public supply it is not desirable to ignore the requirements of important industries, especially if these will be dependent upon such supply for the water used in their manufacturing processes.

In most towns there are numerous factories using steam power, and for boiler purposes a soft water, providing it is free from acid, has many advantages—in fact, such a water is most generally useful for all purposes.

An acid water corrodes boiler-plates, and the greater the degree of acidity the more marked is the action.

An alkaline water—that is, one containing sodium carbonate—is well adapted for use in steam boilers provided it does not contain the alkali in excess and is not in other respects objectionable, but for many dyeing processes such waters are very undesirable. It is asserted that the strongly alkaline waters used in many parts of Essex have an injurious effect upon plants if used for watering purposes.

Hard waters affect boilers in different ways, according to the nature of the salts causing the hardness. Magnesium and calcium chlorides are particularly objectionable, as at the high temperature attained some dissociation takes place, and the hydrochloric acid produced corrodes the boiler-plates. Sulphate of calcium is practically insoluble in superheated water, and is deposited in a hard crystalline condition on the boiler-plates, forming an incrustation which is not only difficult to remove, but also causes a great waste of heat. If the water contains clayey matter also, the incrustation is harder and still more objectionable. Calcium and magnesium carbonates are deposited rapidly after the water enters the boiler, but rarely form a scale. They sink in the form of more or less gritty particles, which are easily removed by 'blowing off.' Sulphate of magnesium in reasonable quantities appears to be unobjectionable in boiler waters. Waters in which the hardness is chiefly due to earthy carbonates are not suitable for many dyeing purposes, forming insoluble compounds with certain aniline dyes, which 'speckle' the fabric. Such waters are also objectionable for hide-washing in tanneries, since the hides having been soaked in lime, carbonate of lime is deposited in the skins, and retards the washing process.

Waters containing sodium carbonate are also said to be unsuitable for the above purpose. Waters, hard from the presence of calcium sulphate, and containing from 2 to 3 grains per gallon of magnesium as carbonate or sulphate, are especially adapted for brewing pale ales, but magnesium chloride is an objectionable constituent in a water used for this purpose. Soft water, on the other hand, is preferable for brewing dark ales, stout, and porter. All hard waters are objectionable for washing and scouring purposes.

An excess of chlorides is said to be objectionable in water used for tanning and brewing; a water which contains much chloride of sodium is without effect upon boiler-plates, but tends to corrode brass fittings, and if stored in cisterns it acts upon the metal at the water-line.

Iron is a very objectionable constituent in a water used for dyeing purposes, or for scouring, paper-making, &c., the oxide being deposited and staining the materials. Water containing any kind of sedimentary matter cannot be used in making the finer qualities of paper.

Waters containing nitrates in considerable quantity have an injurious effect on boilers, the metal becoming oxidised, and ammonia being given off with the steam. For baking and dairy purposes, and for the manufacture of high-class gelatine and other articles likely to be used for human consumption, the water should be of good quality bacteriologically as well as chemically.

Speaking generally, however, the water best adapted for ordinary domestic purposes is the best for technical purposes.

Nearly all waters contain salts of calcium, magnesium, potassium, sodium, and ammonium, in the form of carbonates, sulphates, chlorides, and nitrates. More rarely traces of lead, zinc, or iron may be found, and nitrites and phosphates. It must be remembered, however, that any soluble salt known to occur in nature may be found dissolved in natural waters, but salts other than those enumerated occur so rarely that they are never sought for in an ordinary analysis.

For most sanitary purposes it is sufficient to ascertain that the salts present are not objectionable either in quality or quantity, and that the water does not contain more than a mere trace of organic matter. When the suitability of a water for any manufacturing purpose is also being considered, a more complete analysis is necessary, including the estimation of all the principal anions and cathions. The physical examination usually precedes the chemical, as the detection of any unusual colour, odour, or taste, or the presence of a deposit, would indicate the necessity for some special examination, or might aid in interpreting the results of the chemical analysis.

Where the object is to detect minute quantities of pollution by sewage or matter of manurial origin, a bacteriological examination is imperative, as the evidence which will be adduced later shows that it is quite beyond the power of the chemist to detect small quantities of such contaminating matter, or rather to distinguish it from organic matter derived from harmless sources.

A bacteriological examination, however, affords no information with reference to the character of the water in other respects; hence it is only of use after a chemical analysis has shown that the water contains no excessive amount of saline matter, and no salts of an objectionable character. Where this is already known, bacteriological examinations need not always be supplemented or preceded by chemical analyses. In all cases where a public supply is under supervision, and only a limited number of examinations can be afforded, bacteriological examinations should be made systematically, and a chemical analysis at intervals.

Where the safety of a supply depends upon the efficiency of filtration, bacteriological examinations are especially important, as by such examinations only can the action of the filters be demonstrated.

It is obvious, therefore, that chemical and bacteriological examinations have their special uses, and that one can rarely replace the other. For sanitary purposes the bacteriological examination is the more important, but in most cases it requires to be supplemented by a chemical analysis, to ascertain that the water does not possess too great soap-destroying power, or any other objectionable chemical qualities.

From time to time waters are found to become infected with low forms of vegetable or animal life, which render them unsightly in appearance, or impart an odour or taste which may be anything but agreeable. In such cases a microscopical and biological examination is necessary. Usually the microscope will reveal the offending organism and give a clue to its identity; but these lower forms of life are so protean in character that occasionally their identification can only be effected after a careful study of their life-history. In certain seasons such occurrences are more common than in others. Recently I received, within a few days of each other, samples from two different public supplies, which had become discoloured from the growth of a unicellular alga, usually known as the Chlorococcus. In one case the growth had occurred in the reservoir, and in the other it had taken place in a filter bed which had been disused for a time. The sand near the surface had become completely covered with the growth, and when the water was again turned on the filter, the organisms were carried through into the general supply.

In America, considerable stress is laid upon the systematic examination of surface waters by biological methods, the number and genera (or sometimes species) of the organisms found being recorded. In this country little study has been made of the low forms of life (save the bacteria) which occur in water, although more reliable information as to the character of a water can be obtained sometimes by this method than by any other.

Briefly summarised analyses are undertaken for the following purposes:

1. To ascertain that the water is free from dangerous pollution, and that it contains no constituents which, either from their quality or quantity, render the water unsuitable for domestic purposes.
2. To ascertain if constant in character, and the extent of its variation.
3. To ascertain if affected in quality by heavy rainfalls or continued drought.
4. To ascertain whether it is suitable for boiler purposes, for certain manufacturing purposes, or for public baths or for dairy use.
5. To ascertain whether it is susceptible to tidal influence or whether excessive pumping affects its character, as, for example, by drawing in water from an adjacent river.
6. To ascertain whether it has any action upon metals and to determine how this can be prevented.
7. To ascertain the purifying processes most likely to make it a pure and wholesome water.
8. To ascertain whether the purifying processes are acting satisfactorily.

9. To ascertain the process best adapted for softening purposes.

10. To ascertain whether the softening is uniformly efficient.

11. To ascertain the best method of treatment if the water contains iron, or if it exerts any action upon metals.

12. To ascertain the cause of any colour or turbidity which may occur either in the water as derived from its source or in the water delivered from the main.

13. To ascertain the cause of any odour or taste which the water may have acquired.

14. In deep well borings to ascertain whether waters reached at various stages differ in character.

Examinations of the source are undertaken for:

1. Ascertaining all the possible sources of contamination, their nature, extent, possibility of removal or improvement.

2. Ascertaining, if an underground water, the direction of the underground flow.

3. Ascertaining in such cases the localities of faults, fissures, and swallow holes, and their connection, if any, with the source of supply.

4. Ascertaining the cause of any variation in the character of the water, discovered by chemical, bacteriological, microscopical or physical examination, as, for example, the occurrence of growths in collecting or service reservoirs, or in the water mains, the influx of tidal water or water from any other objectionable source, increase in hardness or in the number of bacteria, or the occurrence of nitrites or other matters not usually found in the water.

The examinations of the source often require to be supplemented by other tests, such as those with fluorescin already referred to. Pumping experiments may have to be made to ascertain whether exhaustive pumping affects the character of the water, and if so, to what extent. Or the water-level may require to be lowered to permit of an examination of the sides of the well and of any adits, and for the collection of samples of the water issuing from different fissures. In the latter case it is desirable to take the temperature of the water entering at various points, as on occasions the information proves useful. By this means recently I was able to locate the source from which polluting matter was entering a mass of chalk and affecting the character of the water. Hot liquor was found to be escaping from the bottom of certain iron cylinders at an adjacent works, and this affected the temperature of the water from fissures in the chalk at some distance from the works.

When well-sinking is in progress samples of water should be examined at intervals and record kept of the water-level in the bore. The utility of such a procedure arises from the fact that waters of very diverse character may be met with at different depths and that it may be highly desirable to shut some of these out.

A boring has recently been made into the calciferous sandstone of the Lower Carboniferous system in order to obtain a supply of water for a certain town. The water first reached was satisfactory in character, and on going deeper the result was successful so far as finding more water was concerned ; but unfortunately, as the subjoined analysis shows, the water was useless for any purpose.

The water contained in parts per 100,000 :

| | |
|---|---|
| Calcium carbonate | 19·2 |
| Calcium sulphate | 39·7 |
| Calcium chloride | 142·9 |
| Magnesium chloride | 62·6 |
| Sodium chloride | 721·2 |
| Silica, &c., and errors | 4·4 |
| Total solids | 999·0 |

The site is over twenty miles from the sea. The boring had to be abandoned.

An interesting example recently occurred in the New Red Sandstone formation where a well was being bored to supply a very large Institution. A sample of water was sent for examination each week as boring progressed and the level of the water in the bore tube was recorded. No use whatever was made of the results at the time, and when the boring was completed and the yield tested, some Authority required proof of the suitability of the water for drinking and general domestic purposes. The water was good chemically, but bacteriologically it was not so good, since by using about 100 c.c. the B. coli was found in it, and the experts differed in opinion as to whether the water was wholesome or not. I was then consulted, and given *carte blanche* to make experiments, analyses, &c., to decide the question. The well was some 400 feet in depth, and a study of the records kept convinced me that water was coming in at three different levels and that these waters varied very much in quality, and that the water coming from the lowest level was the purest and softest. There was a churchyard near on one side, and a sewage farm not far away on another, and these were regarded as possible sources of pollution. I had trial holes bored in the sandstone at intervals all round the well, and appliances fixed for recording the water-levels. The pumps were then set to work to vary to the utmost the water-level in the well. The result of the trial pumping showed that only one boring, not near either the churchyard or sewage works, was affected, but in one bore the water-level rose and fell without the slightest connection with the rise and fall in the well. Inquiry showed that the rise and fall in this bore exactly synchronised with the pumping operations at another well a quarter of a mile or more away. It was certain, however, that water from the more superficial strata of the sandstone was entering the well, and I recommended that this should be shut out. As there were proofs that the water entering at a lower level was very hard, yet not very abundant, it was decided to cut this out also. I estimated the depth at which the sealing would have to be made, and the well-sinker finally concluded that he could do what was required. He was perfectly successful. The result was that the yield of the well was not seriously diminished, that the hardness of the water fell to nearly half, and that both chemically and bacteriologically the water was of the very highest degree of purity. Samples of the water have been examined every month since, and the average number of bacteria found per c.c. is under five, and the B. coli has never been detected, although litres of water have been tested. In this case, if careful records had not been kept, the well would probably have had to be abandoned. I have reason to believe that wells have been bored and abandoned simply because a little expense was not incurred in having the works properly superintended.

Whilst referring to this subject, it may be well to remark that when trial pumpings are being made of new wells, samples of the water should be examined soon after pumping has commenced and again just before it ceases. In this manner any change in the character of the water would be detected. In a recent instance where there appeared to be some danger of insuction of salt water, the Local Government Board asked for a daily analysis to be made on fourteen successive days, pumping being continued day and night for that period without intermission.

Once again let me emphasise the importance of having public supplies examined at frequent intervals and under different conditions, especially during prolonged droughts and after heavy rainfalls. The variations in the different constituents can then be recorded, and afterwards any abnormality is readily detected. The seasonal variation in some supplies is very marked; in others, season has no appreciable effect. The information obtained from 'charting' such results is of the greatest service to the analyst in interpreting the results of his analyses, and I have known such records, in some cases, prevent a supply being condemned, and in others afford the earliest indication of the supply becoming contaminated.

Before proceeding to discuss the results obtainable by the various methods of analysis, let me also again emphasise the importance of the inspection of the source of supply, both in detecting possible sources of pollution and in enabling correct inferences to be drawn from the results of the chemical, bacteriological, and microscopical examinations. This is now being recognised by sanitarians generally. In fact, Gruber, of Vienna, lays so great stress upon an examination of the source, as to assert that in ordinary cases even a bacteriological examination of the water can be dispensed with, and Flugge considers that an inspection of the source and arrangements of the water supply, carried out with the unaided senses, is the most desirable method, and seldom needs to be supplemented by chemical, bacteriological, or microscopical investigations. Dr. Brown, reporting to the Massachusetts Board of Health (1890), says: 'To determine whether or not a water has been polluted by sewage, a chemical analysis is sometimes insufficient, sometimes it is superfluous. It does not need a chemical examination to decide whether a stream has been polluted by sewage when one can see the sewage flowing into it.' And, again, 'Standards are relics of days in which the harmfulness of a water was supposed to be the direct result of the injurious action of specific substances found in it. The theory of to-day is that it is (in the large majority of cases) to the presence of micro-organisms in water that its harmful influence is due, and that the results of chemical analysis have their highest value in the light that they throw on the quality of the water from the standpoint of bacterial contamination.' 'An opinion regarding the wholesomeness of a water must be based on all the information obtainable about it, such as location, environment, and source of the water, and the character and population of the drainage area.'

Frequently it is quite unnecessary to make a detailed and complete examination of a sample of water, and before describing the various processes involved in such an examination, it is desirable first to consider what information is obtainable by each of such processes. It is only when this is known that the analyst is in a position to decide what processes to adopt in any particular case, and to correctly interpret the results of his examination. These various processes may be divided into four groups, viz., Physical, Chemical, Bacteriological, and Microscopical and Biological, and I propose considering them in this order.

# CHAPTER VII

## INTERPRETATION OF THE RESULTS OF THE PHYSICAL EXAMINATION

The physical examination includes colour, brilliancy or degree of turbidity, odour, and taste. Occasionally a determination of the specific gravity is desirable, but such a determination is only of interest when waters highly charged with saline matters are being examined.

**Colour.**—All waters, clarified by filtration if necessary, submitted for examination will exhibit some colour when examined in bulk, as in a glass tube two feet long. The purest waters exhibit a pale sky-blue tint only, the less pure have a colour shading from greenish blue to yellow and reddish brown.

Lord Rayleigh, as the result of numerous experiments made with waters from all parts of the world, concludes that the natural colour of water is a pale green, and that the blue tint often observed is due to reflections from the sky. I obtained for him a softened water which in the tanks had a beautiful sky-blue colour, but in Lord Rayleigh's tubes, 15 feet long, this colour could not be discovered. Still I am convinced that the colour is not a sky reflection, for it is just as marked in the lime tanks which are completely enclosed and only lighted with louvre boards. Moreover I have had my attention directed to the fact that at certain seasons both the water in the lime tanks and in the softening tanks becomes quite green whether the sky above is overcast or perfectly blue and unclouded. The colour is possibly due to some substance present in a colloidal condition. The 'Transactions of the Association of Water Engineers' for 1910 contains an interesting paper on the colour of waters by Professor Kemna, which can be referred to with advantage by anyone interested in the subject. Whilst both chemical and bacteriological examinations require time and skill, a colour test can be applied in a few minutes, and by this means it is often possible to detect a change in the character of the water which may indicate that a filter bed has gone wrong, or that the rate of filtration wants reducing or that some other point requires attention. As a rule, waters with a decidedly yellow colour will be found to contain appreciable traces of organic matter, and when waters from the same source, as from a river, are being regularly examined, the variations in colour often serve as indices of quality. The red-brown colour due to peat is very characteristic, and the presence of traces of iron may often be inferred from the yellowish red tint. Any unusual colour observed would indicate a special examination to ascertain its cause.

The colour of the water supplied by the various London Water Companies was recorded by Sir W. Crookes and Professor Dewar in their monthly report to the *Water Examiner*, under the Metropolis Act, 1871. In a note appended to the Table giving the results of the colour test, they said: 'The ratios show the proportion of brown to blue in the water, the figures representing millimetres in thickness of the respective standard solutions. Thus 10:20 would express a colour composed of 10 millimetres of brown solution superposed on 20 millimetres of blue solution.' The present examiner to the Metropolitan Water Board continues to record these observations.

The following Table, compiled from the returns for the year 1910–11, shows that there is some general correlation between the colour and the amount of organic matter in the various London supplies. The figures are the averages for the year.

| Source of Water. | Colour. Brown. | Colour. Blue. | Oxygen required by organic matter. |
|---|---|---|---|
| New River | 11·0 | 20 | ·0495 |
| East London (Lea) | 17·0 | 20 | ·0839 |
| East London (Sunbury) | 18·0 | 20 | ·0784 |
| Chelsea | 21·0 | 20 | ·1011 |
| West Middlesex | 21·0 | 20 | ·1000 |
| Lambeth | 21·0 | 20 | ·1007 |
| Grand Junction | 16·0 | 20 | ·0789 |
| Southwark and Vauxhall | 19·0 | 20 | ·0919 |
| Kent Wells | 0·0 | 20 | ·0079 |
| Raw Thames Water | 75·0 | 20 | ·2402 |
| Raw Lea Water | 82·0 | 20 | ·2464 |
| Raw New River Water | 38·0 | 20 | ·0900 |

The next Table, giving the average of the monthly examinations of two of the supplies, shows, however, that there are many exceptions to the rule that the depth of the brown tint varies with the amount of the organic impurity.

| PERIOD. | NEW RIVER. |  | EAST LONDON (R. LEA). |  |
|---|---|---|---|---|
|  | Colour. Proportion of brown to 20 blue. | Oxygen required by organic matter. | Colour. Proportion of brown to 20 blue. | Oxygen required by organic matter. |
| Average 1909–10 | 11 | ·0495 | 17 | ·0839 |
| April, 1910 | 9 | ·0373 | 14 | ·0555 |
| May | 10 | ·0336 | 14 | ·0541 |
| June | 9 | ·0313 | 14 | ·0582 |
| July | 8 | ·0332 | 14 | ·0626 |
| August | 7 | ·0223 | 13 | ·0530 |
| September | 6 | ·0207 | 12 | ·0463 |
| October | 8 | ·0190 | 13 | ·0426 |
| November | 10 | ·0374 | 15 | ·0563 |
| December | 19 | ·0851 | 20 | ·0900 |
| January, 1911 | 15 | ·0555 | 21 | ·1012 |
| February | 9 | ·0312 | 16 | ·0730 |
| March | 14 | ·0544 | 15 | ·0625 |

The oxygen absorbed is expressed in parts per 100,000.

With experience, fairly correct inferences as to the quality of a water may often be drawn from an examination of its colour. The Medical Officer of Health or Sanitary Inspector, making inspections of districts supplied with water from shallow wells or similar sources of supply, may be guided in their selection of samples for analysis by viewing some of the water in a deep tumbler placed on a sheet of white paper. Those in which a yellow tint is observed are the most likely to be impure, and therefore to require further examination. It must not be forgotten, however, that highly nitrated waters are often beautifully clear and free from colour.

**Brilliancy or Turbidity.**—A water from a public supply should always be free from visible floating particles, and be bright and clear even when viewed in bulk. If such is not the case the cause should be ascertained. Waters which at one time are clear and bright, and at others dull or turbid, should always be looked upon with suspicion. If particulate matter can gain access to the source of the water, then obviously the specific organisms causing disease may also be admitted. Turbidity appearing soon after rain, especially if the source is in proximity to drains, cesspools, ditches, or manured ground, indicates serious danger of pollution, and therefore that the source of supply is unsatisfactory. In such a case the sample selected for further examination should be taken when the water is turbid. Owners of wells often express their anxiety to have a 'fair' sample examined, and for this purpose collect it when the water is brightest.

An analysis of such a sample may be seriously misleading, and reliance thereon has often proved disastrous. The strength of a chain is that of its weakest link, and the quality of a water supply is measured by the worst sample which can at any time be obtained from it. The turbidity may be due to suspended chalk or oxy-carbonate of iron, in which case it disappears when treated with acid. Clay is unaffected by dilute acid, and the water clarifies very slowly on standing. A chemical and microscopical examination is generally needed to show the nature of the suspended matter, and such examinations often yield valuable information.

The cause of a temporary discoloration or of some odour may usually be discovered by aid of the microscope, and sewage contamination is occasionally revealed by the discovery of starch granules, and of vegetable and animal fibres (silk, cotton, wool, &c.). Quite recently considerable alarm was experienced by the customers of a Water Company and by the directors of the company on account of the appearance of minute 'worms' in the water from the mains. As the source could not be discovered I was called in, and found the so-called 'worms' to be the larvæ of gnats which had been deposited in an uncovered service reservoir.

Water from wells recently sunk often contains suspended mineral matters, but after use for some time such waters generally become clear, the finest particles of mineral matter in the water-bearing strata having been removed by the continuous flow of water into the well. An analysis of a water taken from a new well always requires careful consideration to correctly predict the character of the ultimate supply.

Waters containing traces of iron salts in solution may be perfectly bright when first drawn, yet speedily become turbid and more or less brown upon standing in contact with air, in consequence of the formation of more highly oxidised and insoluble salts. Usually such waters have become turbid before reaching the laboratory, in which case the turbidity disappears quickly on the addition of acid, and the further addition of a suitable reagent reveals the presence of iron.

Colour and turbidity can generally be determined together. All filtered waters should be examined daily or twice or thrice a day, if mechanical filters are in use. By this simple test imperfect filtration can often be discovered and then promptly remedied. If the persons in charge of such installations had to keep records of the results of systematic observations it would be an advantage to the owners, whether a private Company or a Sanitary Authority, and also to the public who consume the water. The information would also be especially valuable when investigating complaints, and would supplement the results obtained by systematic chemical and bacteriological examinations.

√ **Odour.**—No water can be satisfactory as a public supply or as a domestic supply if it possesses an odour of any kind. Even when warmed and shaken no odour should be obvious. A possible exception is in the case of moorland waters containing a trace of peat, but even such a water would be objectionable if when warmed the odour were very decided. Occasionally waters are met with which are of a high degree of purity, and free from any excess of saline matter, yet have a more or less decided odour of sulphuretted hydrogen. These waters occur locally, and especially in districts on the boulder clay. The smell disappears quickly when the water is allowed to stand exposed to the air. The offensive gas is probably produced by the reduction of sulphates, but whether by some inorganic reducing agent or by living organisms, I have not been able to ascertain. Wells yielding such waters are always discarded sooner or later under the impression that the water is sewage-polluted, and no series of chemical analyses can remove the impression.

River waters often have a faint earthy smell, but in such cases the water is almost invariably polluted with sewage or manurial matter. Decomposing animals may impart an unpleasant odour to water. Small eels have been known to get into water mains, and dying there have tainted the water. Dead fish may affect pond water, and animals which have been accidentally drowned in house cisterns may only be discovered by their effect upon the water passing through. In most cases, however, when a water becomes tainted the odour is due to some low form of vegetable life, and it is often difficult to decide to what particular organism this is due. The odorous substance may be the volatile products formed by the living plant, and these may either be excreted during life or be liberated only when disintegration occurs; or the odour may be due to putrefactive changes occurring in the organic matter in the water due to the development of certain bacteria. In some cases the odour is accentuated by heating and is persistent, in others the odour speedily disappears when the water is warmed.

The organisms producing odours are usually found first in open reservoirs and, if the water is not efficiently filtered, they find their way into the mains, where in the absence of light and air they perish and undergo putrefactive changes. Hence the reservoir water may be odourless, while that delivered to the houses may have a vile odour. The autumn is the usual time for such organisms to appear, but the special conditions leading to the infection of a large volume of water are not known.

A few years ago quite a number of wells in Essex developed odours during the autumn, which I attributed to a general infection by a species of crenothrix. All these waters contained a trace of iron, and were not of a high degree of organic purity, but most of them were free from suspicion of sewage pollution, although the odour was strongly suggestive of sewage.

A list of the organisms to which the production of odours in drinking waters has been attributed is given in the section on the microscopical examination of water, and further details of this subject may be found in my book on 'Water and Water Supplies,' Chapter VIII. Since my attention has been called to the matter I have concluded that the acquisition of an odour by a water supply is not so rare as is usually believed, though apparently much more rare in this country than in others, where less trouble is taken to secure and maintain a pure supply. Unless the odour is so marked as to give rise to numerous complaints, it is ignored, and as in most cases the odour disappears in a few weeks, a thorough examination is rarely deemed necessary. Many samples of water are sent for examination on account of some peculiar odour having been observed, yet these samples when received at the laboratory are quite free from smell. In some cases it is found that the water first drawn from the pump or tap had the curious odour, the water drawn afterwards being quite free from smell. In these cases the smell has been suggestive of impure hydrogen produced by the action of zinc or iron on a dilute acid, and certain waters, if allowed to stand a few hours in an iron pipe or a galvanised iron pipe, acquire this odour, which speedily disappears when the water is exposed to air.

All water authorities receive complaints from time to time of the water having some odour and often on such occasions there is some turbidity. Generally it is the turbidity which first attracts attention, and when suspicion is aroused that something is wrong it is an easy matter to detect an odour, even if only existent in the observer's imagination. In most of these cases there is some cause of stagnation in the mains resulting in the gradual accumulation of sedimentary matter and in the growth of low forms of vegetable life, the ultimate decay of which may result in the formation of an odoriferous substance. Flushing the main is the usual and effectual remedy.

It is surprising how often smells can be perceived when a water is being drawn off rapidly, and especially if it is hot, when such smell is not perceptible in the small quantities sent for analysis. No doubt, in some cases the odoriferous body has undergone decomposition during transit. This is especially the case when the odour is due to $H_2S$. In the instance referred to on page 20, where complaints were received that when a bath was being filled with the water there was a smell suggestive of 'gas,' only a person here and there noticed it, and several samples sent to my laboratory had no such odour. Finally one was obtained which, for a short time, had a faint odour. Some said 'gas,' others 'petrol,' others 'india-rubber tubing,' and others could not name it. It became certain, however, that the water on occasions had an odour and that it was not purely imaginary. As previously stated, an examination of the well and more detailed analyses of the water proved a connection between the gasworks and the well.

Probably the most common cause of complaint is that of an odour of tar, due to the laying of new mains. If the mains have been properly coated and matured the smell (and taste) rapidly passes off, but if the coating is unsatisfactory and has not properly dried and hardened it may continue to affect the water for twelve months. When a water undertaking is being inaugurated it is a serious matter to provoke prejudice in the minds of the future consumers by using unsatisfactory pipes. In one instance, where foreign pipes were used, the water was discoloured and rendered objectionable to taste and smell for about a year, and it was not until several years afterwards that the inhabitants of the district began to have their houses connected with the mains. The dividend-paying period was deferred years by this unfortunate commencement. The yarn often used for caulking pipes occasionally imparts odour and taste to the water.

Frequently samples of water sent in unclean or imperfectly cleansed bottles have a decided odour—it may be of beer, of wine, of spirits, or sour milk; and in one case the water had not only the odour of carbolic acid, but upon examination it was found to contain an appreciable trace of that poison. To examine such samples is often a mere waste of time, or worse, as the results may lead to an erroneous inference. It is exceedingly difficult to explain to the senders of the samples that the analysis of such a water cannot be satisfactory. 'Surely,' said one man, 'you can tell the difference between a drop of whisky and a drop of sewage.' How can an analyst admit the limitation of his powers under such circumstances? Some years ago a gentleman brought me a sample of water taken from his pump. The water, he said, had recently become turbid and acquired an offensive smell. Finding the water had a distinct odour of putrid sewage, I advised him to spend his guineas in having the well and its surroundings examined. I received neither fee nor thanks for my advice, and have since concluded that in such cases it is better to take the fee and, after making the analysis, give the advice. The advice, having been paid for, is then much more likely to be acted upon. In a recent instance a lady sent a sample of water for analysis, and in order to make certain that the bottle was clean, she gave it a final rinse with strong solution of ammonia. The analytical results were so extraordinary that I sent an assistant for another sample of the water, and it was when taking this that the lady explained how she had made certain of the cleanliness of the bottle she had used.

**Taste.**—Odorous waters are usually said also to have a peculiar taste, but doubtless this is often imaginary. As I very rarely taste a sample of water sent for analysis, I cannot speak with authority on the subject. Rain-water, unless well aërated, has undoubtedly a mawkish taste. Peaty waters also have a characteristic flavour, and ferruginous waters always leave an inky flavour in the mouth. The odour and taste due to the coating and caulking of the mains has already been referred to. Water containing an unusual quantity of salt, whether derived from the water-bearing stratum or from infiltration of sea-water, may have a brackish taste. The susceptibility of various palates to the presence of salt varies very considerably. When sea-water has been infiltrating into a public water supply, some persons have detected it and complained when the amount of salt did not exceed 20 grains per gallon; others have not noticed it until it has reached 50 or more grains per gallon. In 1903 I had to decide whether the water from a deep well in the chalk, on which nearly a thousand pounds had been expended, was suitable for a public supply. It contained 83 grains of sodium chloride per gallon. The taste of the salt was distinctly evident to me, but many persons who tasted it could not detect it. I expressed the opinion that such a water was not suitable for a public supply, and this opinion was upheld on appeal to the Local Government Board. The sequel is worth mentioning. Another site was selected in the same parish, and a second bore put down. This yielded a very much more abundant supply, and the water only contained 48 grains of salt per gallon, a permissible quantity. In this instance it was known that the deep wells to the north all yielded brackish water, whereas those to the south contained much less salt. The engineer, however, had sunk the well towards the north of the parish because of the ground being higher, and therefore suitable for having the well and the service reservoir in the same curtilage. I selected the low-lying ground to the extreme south because experience had taught me that water was more freely obtainable where the chalk was only covered by a thin bed of clay, and that the water in such localities was less likely to be saline.

I have now, however, had to alter my opinion to a certain extent with reference to such waters as the result of an enlarged experience. In certain parts of Essex the only available water is that of the character described above, and it is used by a considerable number of persons. A newcomer always objects to it at first, but soon becomes accustomed to its use, and experiences no ill effects from drinking it. I certainly should not recommend such a water were a better available, but where it appears impracticable to obtain any other water, I see no serious objection to its being utilised as a public supply, especially if a pure and abundant supply is greatly needed. The salinity is due to the infiltration of sea-water, but the lime and magnesia salts have almost entirely disappeared, these bases being replaced by soda derived from the Thanet sands. The peculiar changes which a hard water may undergo by filtration through certain minerals will be referred to in a later section.

Waters differ considerably in taste, some being much more palatable than others. A person accustomed to the use of a hard water finds a soft water more or less unpalatable for a time, and *vice versa.* Waters containing much sodium carbonate have a 'soft' flavour, liked by some, disliked by others. Ferruginous waters have an inky taste; waters containing much salt have a brackish taste. An excess of sodium sulphate gives a cool saline flavour. Probably the most palatable waters are those containing nitrates and carbonic acid, waters which may have been derived from objectionable sources, the nitrates and carbonic acid being formed by the thorough oxidation of sewage and manurial matter. Such waters also are usually colourless, bright and sparkling, and therefore may be highly esteemed. When a well yielding such a water is condemned as being liable to dangerous pollution, people will still continue to use it in preference to a supply derived from a main, which, to them, is far less palatable. The sense of taste varies very much with different individuals. As we have seen, some persons can detect the presence of 20 grains of salt per gallon, whilst others fail to detect it when 70 grains is present. Others can detect very minute traces of iron, while others cannot taste it, although there may be sufficient present to give an inky appearance when used for diluting whisky or brandy.

When water has been treated with an infinitesimal trace of chlorine, some can detect it, whilst others do not. In this case there is a peculiar effect upon the hard palate which can scarcely be described as 'taste.' As a rule the taste of a water is not recorded, unless the water has also an odour, when in the majority of cases it will be said to have a taste, although such taste will not be detected if the nostrils are closed. In selecting a source of supply, however, palatability should be considered; other things being equal, the most palatable water being selected. Unfortunately, however, the opinion of the chemist may not be shared by the consumers, so that a guarded opinion only should be expressed.

# CHAPTER VIII

## INTERPRETATION OF RESULTS OF CHEMICAL EXAMINATIONS

(*a*) **Reaction.**—As a matter of routine, it is desirable to ascertain whether a water has an acid reaction or possesses the power of neutralising acid, since if it does not possess this power it may have an action upon metals, and it is important to determine whether this is the case or not. The waters which act upon lead, iron, or zinc are those which either are distinctly acid in reaction, or contain less than three or four parts of sodium, magnesium, or calcium carbonate per 100,000. Such waters have not more than three or four degrees of temporary hardness. A water of low temporary hardness may, however, contain sufficient sodium carbonate in solution to prevent any action on metals (*vide* section on the action of waters on metals).

The acidity in practically all cases is due to carbonic acid. In many instances in which waters acted upon lead I have endeavoured to ascertain whether any other acid is present, but invariably with negative results. The determination of the amount of carbonic acid present, over and above that necessary to convert the carbonates in the water into bicarbonates, is probably of greater importance than is generally realised. This free acid exerts an action upon metals, dissolving lead, zinc, and iron from pipes and cisterns, and corroding boiler-plates. An excessive amount is sometimes found in hard waters, in which case the water has an action upon lead shot, which may continue for days, but ultimately ceases. An estimation of the carbonic acid is also necessary when a water is being examined in order to ascertain the amount of lime, or lime and soda, which will be required for softening purposes.

(*b*) **Residue Left on the Evaporation of a Water.**—In good waters the residue left on evaporation over the water-bath is quite free from colour. In other waters the opacity of the residue and the effects produced by more strongly heating it (decrepitation, fusion, discoloration, &c.) all convey information to the intelligent and experienced observer. Charring indicates the presence of organic matter, and, if accompanied by a disagreeable odour, generally indicates that this organic matter is of animal origin. When merely a trace of such matter is present, there may only be an evanescent browning or blackening, usually most evident towards the periphery of the saline residue. When there is an abundance of nitrates present, the organic matter may be decomposed without any obvious charring or discoloration. The presence of iron is usually indicated by the brown tint of the residue, rendered more evident upon ignition. If the analyst uses constantly the same quantity of water for evaporation, he can at a glance tell if the saline residue is excessive in amount, and often it is merely necessary to state whether this saline residue is excessive or otherwise, without determining its exact quantity. For this purpose some knowledge of the source of a water is necessary. An upland surface water should leave an exceedingly small residue, five or six parts per 100,000, whereas water from the chalk and other formations may give many times this quantity. In Essex we have large public supplies deriving water from the Thanet sands and chalk, giving as much as 150 parts of solid residue per 100,000. The quality as well as the quantity of the saline constituents is of importance; hence, if the determination of the hardness, chlorides, and nitrates does not account for nearly the whole of the saline matter, a more complete analysis is desirable. For example, the Essex waters above referred to often have a hardness of a few degrees only, and contain the merest trace of nitrates, while the chlorides may not account for half the total saline matter. Further analysis shows that the waters contain large quantities of sodium carbonate and sulphate, neither of which is estimated in an ordinary analysis.

A properly made quantitative estimation of the total solids affords a valuable check on the results of the more detailed analysis, whilst a qualitative or rough quantitative estimation often affords interesting information with regard to the quality of the water.

The saline constituents found in waters from various sources are given in the Tables of Analyses. In an ordinary sanitary analysis, only the chlorides and nitrates are usually estimated, but the estimation of the total permanent and temporary hardness gives some rough indication of the amount of the calcium and magnesium compounds present, and of the proportion existing as carbonates. Tests are applied for detecting the presence of nitrites. When present, the amount is invariably very minute, and a quantitative estimation is very rarely made. The above estimations frequently furnish all the information which is required with reference to the nature of the saline constituents of a water.

(*c*) **Chlorides.**—In most waters, the whole of the chlorine present is in combination with sodium as sodium chloride, but occasionally calcium and magnesium chlorides are also present. I have only found potassium chloride present in appreciable amount in waters containing such other constituents as would place them in the category of mineral waters. Such being the case, the amount of chloride present will closely approximate to the amount of chlorine multiplied by 1·65 (or divided by 0·6), but it is usual to express the chlorides in terms of chlorine. Thus a water containing 6 parts of chlorine per 100,000 will contain approximately 10 grains of sodium chloride, if the whole is combined with sodium, and very little less than 10 grains of mixed chlorides if a small portion is combined with calcium or magnesium. The error only becomes marked if there is much magnesium chloride present, as is very rarely the case unless sea-water is gaining access to the supply examined. This is obvious from the fact that 35·5 parts of chlorine represents 58·5 of sodium chloride, 55·5 of calcium chloride, and 47·5 only of magnesium chloride, these salts containing 60·0, 64·0, and 74·6 per cent. of chlorine respectively.

Practically all soils and rocks contain chlorides, in quantities varying from the merest trace to the rock salt formation, which consists practically of pure sodium chloride. Hence all waters, including even the purest rain-water, which derives a trace from the air, contain chlorides. Besides their natural source, chlorides may, in the neighbourhood of the sea or tidal rivers, be derived from sea-water which has entered the water-bearing stratum. Sewage and urinary matter from stables and byres contain chlorides. Occasionally also land is salted for certain agricultural purposes, and I have known this appreciably affect the amount of chlorides in the subsoil water. Some years ago I examined a sample of water from a shallow well sunk to supply a mansion, and found so much salt in it that I went over and examined the site. The well, which was only about eight feet deep, had been sunk in a field far from any possible source of pollution. There was nothing to explain the presence of all this salt, and another well, sunk in a different part of the field, yielded a water containing a far smaller quantity, yet much greater than the other shallow wells on this patch of gravel. The only possible explanation was the ‘ salting ’ of the field, but that this had been done was denied by the tenant of the field.

As a rule, however, the amount of chlorides from a given stratum and in a particular locality varies only within narrow limits, but in many districts the variation is sufficient to render it impossible to say that any slight difference observed is due to sewage contamination.

Urine contains nearly 1 per cent. of sodium chloride, and the whole of the sewage of 1000 people deposited on a square mile of porous gravel would not increase the amount of sodium chloride in the gravel water by, on an average, more than 0·5 part per 100,000. In Massachusetts an attempt has been made to map out the country into areas of equal chlorine contents in the unpolluted waters. The points of equal amounts when connected are termed *isochlors.* The waters near the coast contain about 0·6 part per 100,000 of chlorine, and proceeding westward from the coast this gradually falls to about one-eighth of the amount. Such small quantities of chlorides are rarely found in this country, and all attempts to map out isochlors have proved futile.

Over limited areas, where the water-bearing stratum is uniform in character and continuous, the amount of chlorides found in localities far removed from the possibility of pollution may be considered as the 'normal,' and any excess found elsewhere in water from the same stratum may be attributed to present or past pollution. In this country, at least, it is practically impossible to obtain water from deep or shallow wells which has not, in its previous history, been in contact with manured soil. The surface soil possesses such oxidising and purifying qualities, due chiefly to the nitrifying organisms therein, and the subsoil usually filters so effectively, that practically the whole of the organic matter and the bacteria derived from the sewage disappear before the water has travelled any considerable distance. As the presence of ashes indicates that there has been a fire, and therefore that organic matter has been consumed, so the presence of an excess of chlorides and, as we shall see later, of nitrates in water, indicates that the water has contained organic matter, presumably of animal origin, but that it has been oxidised or burnt. Unless some of this organic matter remains unoxidised, or the bacteria which accompany it are not removed by the natural process of filtration, the water may be perfectly wholesome. The chlorides and nitrates are the ashes of the organic matter of sewage, as carbonates, silicates, &c., are the ashes of wood.

Several times I have had occasion to examine the water from every well in a parish, and have always found great variations in the amount of chlorides, the amount increasing towards the centre of population, and in the direction of the flow of the subsoil waters. Taking 4 parts of chlorine per 100,000 as the normal, the amount often increases to 20 or upwards. In all cases this increase of chlorine is accompanied by an increase of nitrates, and in most cases by an increase in the amount of ammoniacal and organic matter. Obviously with such an amount of chlorides, derivable from no other source than sewage as far as could be ascertained, the ground water must have consisted almost entirely of sewage more or less purified. Such a polluted subsoil is utterly unfitted to serve as a source of water supply. As a rule sewage contains about 5 parts of chlorine per 100,000 above that found in the water supply, allowing 30 gallons of water per head per day ; hence in cases such as the above, where the chlorine rises to 20 parts, the amount of water used daily must have been very small, or the same water must have been used over and over again, each time becoming more highly charged with sewage or the products of its oxidation. The amount of chlorides found in potable waters varies so much that safe conclusions as to their source cannot be drawn without confirmatory evidence. If derived from sewage this evidence can be obtained by determining the amount of nitrates in the water. If they are so derived, nitrates will also be present in marked quantity and the amount of both will rise and fall together. Hence, when a water contains a large amount of chlorides and a correspondingly large amount of nitrates, the origin of both may be said to be certain. Occasionally further proof can be obtained, as in the remarkable instance briefly referred to on page 21. Here the well yielded an unfailing supply of water, which was used for all domestic purposes, and upon analysis it was found to be remarkably free from organic matter. It was said to be always cool, bright, and sparkling, probably due to its containing a very excessive amount of chlorides and nitrates, derived from the sewage percolating into the subsoil, and I expressed the opinion that the water was a concentrated, purified sewage. This was not believed at the time, but when the cesspool was filled in and the sewage carried elsewhere, the well ran dry. There is no doubt that in this case the same water was used over and over again. After being defiled by the closet, slops, &c., it ran into the cesspool, then filtered through the soil, in its progress the organic matters becoming completely oxidised, and ultimately it found its way back to the well, to be utilised again for domestic purposes. Doubtless at times, possibly after heavy rains, the cesspool contents filtered too rapidly for complete purification to be effected, and this impure water may have been the cause of the ill-health amongst those who consumed it.

The same kind of thing is going on in thousands of villages where the cesspools allow their contents to percolate into the subsoil water which supplies the wells from which the domestic supply is obtained. Were it not for the remarkable purifying action of the soil, epidemics of typhoid fever would be far more common. As it is, communities continue to use such waters, and often on account of their cool and pleasant taste, and bright sparkling appearance, they prefer them, even after a public supply of pure water has been laid on.

Near the sea the influx of sea-water will be indicated by an increase in the chlorides, but to prove this it is necessary to estimate the magnesium in various samples to ascertain if this increases *pari passu* with the chlorine. The 'hardness' will increase also, the temporary hardness very slightly, the permanent hardness more markedly. Analyses (*vide* Tables) of Gosport waters may be referred to as examples of waters affected by impregnation of the subsoil with tidal water. The chlorine in sea-water is about 1885 parts in 100,000; hence the infiltration of 1 per cent. will increase the chlorine in a water by 18·55 parts per 100,000. The chlorides in tidal rivers vary very considerably, decreasing as the river is ascended. Between Woolwich and Leigh, on the Thames, I have found it to vary from 900 to 1800 parts per 100,000, but higher up the river it becomes very much less. The detection of the presence of tidal water is of especial importance if such water is known to be sewage-polluted, but here again the percolation through the soil or rock may have removed practically every trace of organic matter. Analyses of waters from Grays (*vide* Tables), affected by the influx of very impure Thames water below the outfall of the London Sewage Works, have only once yielded results indicative of sewage contamination, although I have made analyses, chemical and bacteriological, of about 100 samples.

Occasionally the decrease in the amount of chlorides in a well water has some significance. In more than one instance I have detected the infiltration of subsoil water into a deep well by the chlorides decreasing. Many Essex deep wells contain a considerable amount of sodium chloride, and in the same well this varies very slightly from year to year. If subsoil water gains access to such wells the chlorides are proportionately decreased. The presence of so much sodium chloride in these well waters has in more than one instance led the analyst astray. In a recent case the chemist gave at length his reasons for believing that the excessive amount was due to sewage pollution. As a matter of fact, the well from which the water was derived was about 1000 feet deep, bored in the open country far from any habitation, where sewage pollution was absolutely impossible. It was one of the purest of natural waters, free from the slightest indication of contamination by either sewage or manure.

In Essex several public supplies contain from 50 to 70 parts of sodium chloride per 100,000, and appear to be quite unobjectionable. I think however that, save under very exceptional circumstances, when the amount reaches 70 parts and is distinctly perceptible to the palate, the limit permissible has been reached. A very much smaller quantity of calcium or magnesium chloride would render a water absolutely useless for many domestic purposes on account of its soap-destroying power, and I should consider even 4 or 5 parts of these salts per 100,000 to be objectionable. These chlorides have a corroding effect on steam boilers; hence where the water is to be used for boilers and other manufacturing purposes, as well as for a domestic supply, their presence is extremely undesirable.

Paper works and other manufactories often discharge large quantities of effluents containing chlorides, and the possibility of any excess found in a river or stream being due to such a cause must not be forgotten.

(*d*) **Nitrates.**—The amount of nitric acid combined with bases present in potable waters is expressed in several different ways. Some chemists express it as hydrogen nitrate ($HNO_3$),[1] others as nitric anhydride ($N_2O_5$), but the majority now express it as nitric nitrogen or nitrogen in nitrates. As one part of nitrogen represents 4·5 of hydrogen nitrate and 3·9 of nitric anhydride, obviously it should always be most distinctly stated what the figures given represent. This is not always done, and difficulty sometimes arises in interpreting analyses from this cause. Throughout this work the term 'nitric nitrogen' will be used to represent the amount of nitrogen present in the nitrates found in water. For some reason there is often considerable discrepancy, as regards nitrates, in the results obtained by different analysts from the examination of the same water. It has been difficult for me sometimes to believe that all had had samples from the same source, yet the other determinations agreed so closely as to preclude any doubt.

It is very probable that practically the whole of the nitrates found in water are derived from the oxidation of nitrogenous organic matter of animal origin. Vegetable matter by oxidation in the soil yields very little nitric acid, whilst animal matter yields a large amount. The nitrogenous bodies of animal origin readily decomposing, probably the whole of the nitrogen ultimately becomes converted into nitric acid, which reacting upon the carbonates in the soil forms the nitrates found in subsoil and deep well-waters. No doubt there are several stages in this decomposition, some being due to the action of the bacteria found in soil, and others to chemical action merely. The breaking down of proteid matter results first in the formation of ammonia, this by nitrifying organisms is converted into nitrous acid, and further oxidation leads to the formation of nitric acid.

The Rivers Pollution Commissioners found that 97 per cent. of the combined nitrogen in London sewage was converted into nitrates by slow percolation through five feet of gravelly soil.

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[1] Chemical nomenclature has undergone many changes during the present generation, and both the compounds above referred to have been called nitric acid.

As average London sewage contains 10 parts of combined nitrogen in 100,000 parts, the latter amount of sewage would yield 9·7 parts of nitric nitrogen. A water containing 10 per cent. of such purified sewage would yield about 1 part of nitric nitrogen per 100,000. The purest rain-water contains a trace of nitrates, on an average equivalent to 0·03 part nitric nitrogen per 100,000. This is probably due to the oxidation of atmospheric nitrogen during electric discharges. Vegetable matter in its comparatively slow decay produces very little nitric acid; hence, as no other source of nitrates is widely distributed, most of the nitrates found in water must have been derived from animal matter, and therefore, in the great majority of cases, from manure and sewage. At one time I was considerably puzzled by the large amount of nitrates found in a certain water supply in Yorkshire, but I ultimately found that the well was sunk near some trenches which had been filled with bodies after one of the battles during the Civil War. Bones in quantity were found here on sinking a pit, and when pumping was going on at the works the water-level in the pit gradually fell, to rise again when the pumping ceased. In another instance, when a well was being sunk a curious stratum containing much organic matter was reached, the water from which was loaded with nitrates. The opinion of the geological expert was that the bed was an old guano deposit. A short time ago I found that the nitrates in the water from a well supplying a country house had considerably increased, and upon inquiry learnt that the owner had had a lame hunter shot and buried in the vine border not many yards away.

The nitric nitrogen occurring in waters used for domestic purposes varies from none to 7 or more parts per 100,000, though few waters are found with either of these extremes. I know a few deep wells, the waters from which are apparently free from nitrates, and the few samples which I have met with containing as much as 7 parts of nitric nitrogen per 100,000 have been from shallow wells, such as those above referred to. On account of this great variation, some analysts ignore the presence of nitrates, regarding the indications afforded by the determinations as having no value. For my part, I do not see how anyone can express an opinion upon a water without knowing approximately the amount of nitrates present, and something about their most probable source. Waters from the Essex gravel beds contain from about 0·4 to 1·5 parts of nitric nitrogen per 100,000, the difference being due to the extent to which the soil is manured. There is also a seasonal variation in waters from the same spring or well, but not nearly so marked as the variation in different gravels. No standard can possibly be adopted as to the amount of nitrates permissible in a potable water. The nitrates are as harmless as the chlorides, and though excess of both indicates previous sewage or manurial pollution, if the sources from which they are derived are sufficiently remote, their presence may be ignored. Chemical analyses cannot be depended upon to tell us anything about the proximity or otherwise of the source of pollution, and most serious epidemics of typhoid fever have occurred amongst populations using water containing very small amounts of nitrates; on the other hand, to my knowledge, many large villages using water containing from 1·5 to 5 parts of nitric nitrogen per 100,000, for the last twenty years at least, have remained free from typhoid fever, save when an occasional case has been introduced from without.

Notwithstanding this, a water cannot be recommended for domestic use which contains much more nitrates than appears to be the normal in the best waters from that particular water-bearing stratum. Any excess necessitates a careful investigation of the source of the water.

When animal matter undergoes decomposition in the absence of air, and in the presence of water containing nitrates, these latter are deoxidised and disappear, consequently nitrates are rarely if ever found in putrid sewage. Ferruginous sand may also reduce nitrates to ammonia, and all growing crops absorb nitrates from the soil. Hence the amount of nitrates in a water may not represent the whole of the previous pollution to which it has been subjected. In the *Journal of the Chemical Society*, August 1886, appears a paper by Dr. Munro on 'The Formation and Destruction of Nitrates and Nitrites in Artificial Solutions and in River and Well Waters.' In this paper Dr. Munro says: 'An excessive quantity of nitrates in water is very generally regarded with suspicion. I am not aware, however, that the *absence* of nitrate has been pointed out as a ground of condemnation. Clear rain-water and the water of mountain streams often contain but a trace of nitrate; well and river water must, however, contain more than a trace, unless some cause has brought about the destruction of previously existing nitrate. This cause is the access of fermentable organic matter to the water, and in most cases the fermentable organic matter is derived from sewage. When, therefore, a water contains enough mineral matter to demonstrate its percolation through soil, and at the same time is free from nitrate, or contains only a trace, barely recognisable by diphenylamine, the occurrence of a destructive fermentation may be inferred. These cases are not uncommon among well waters.' I do not agree with Dr. Munro in thinking these cases are common amongst well-waters, but as they doubtless do occur, care requires to be exercised in expressing an opinion, even when the amount of nitrates present is very small.

MM. Gayon and Dupetit have made a special study of two organisms, which they call Bacterium denitrificans '*a*' and '*b*,' which reduce nitres with the production of nitrogen gas. They were obtained from a sample of sewage. They are facultative aerobes, and in the absence of a free supply of oxygen they reduce nitrates, and if, and only if, there is nitrogenous organic matter also present they produce ammonia. Nitrites are said to be first formed, but a minute quantity only is discoverable, and this quickly disappears. Where nitrates are in process of formation or of reduction, traces of nitrites are generally found, hence some analysts lay great stress on the test for the presence of nitrites. It is generally advisable to submit a water containing an excess of nitrates to a bacteriological examination, the sample being taken a day or two after a heavy rainfall, in order to ascertain whether both soil purification and filtration are efficient. A water which contains any excess of nitrates, and which is liable to become turbid or opalescent after a heavy rain, should be unhesitatingly regarded as unsafe for domestic purposes.

(*e*) **Nitrites.**—Nitrites are nearly always found in sewage effluents from the so-called bacteria beds. Their presence indicates that the organic matter in the sewage is undergoing active oxidation or nitrification, and that the process is not complete. Hence, as nitrites are rarely found under other conditions, a water containing a trace, however slight, must be regarded with grave suspicion, unless some other source is found from which they have more probably been derived.

Dr. Munro, in the paper previously quoted, says: 'Although nitrite is very easily formed both by oxidising and reducing fermentations, it is very rarely present in natural waters, except in very minute traces. It may exist in a water because the conditions do not favour complete nitrification of the ammonia, and in this case the water may be clear; or, because of bacterial reduction of the nitrates, caused by an influx of almost any organic matter—in this case the water is not clear. The reason why nitrite, formed by reduction, is not often found in well-waters is that in most cases the organic matter provoking the reduction consists of sewage, and . . . sewage contains bacteria, which speedily destroys both nitrate and nitrite with liberation of nitrogen gas.'

In partially purified sewage containing nitrites, an excessive amount of free ammonia is also found, but unfortunately other sources of nitrites besides sewage also produce ammonia, so that this fact does not throw any light on the origin of the nitrites. As previously stated, many waters containing nitrates, if allowed to stand in contact with iron, zinc, or lead in pipes or cisterns, act upon the metal, the nitrates being in part reduced to nitrites and ammonia. Ferruginous sand may also effect this reduction. In such cases careful tests will detect some trace of the metal in solution. Unless, therefore, indications are obtained of the presence of an inorganic reducing substance, the nitrites must be attributed to the imperfect oxidation of animal matter, and the water be condemned as unwholesome or dangerous.

The possibility of nitrites being derived from any other source than sewage or manure is too often ignored, and has led to many waters of perfectly satisfactory quality being reported as sewage-polluted. That this reduction of nitrites by metals is a comparatively frequent source of nitrites, I have proved by numerous experiments made for the purpose; and when applying tests to ascertain the action of water on metals, I have practically always found that the oxidation of the metal was accompanied by the reduction of the nitrates.

Besides the micro-organisms found in sewage and manures, which, in the absence of air, are capable of deriving the oxygen necessary for their development from any nitrates present, there are, probably, similar reducing organisms not derived from such objectionable sources; for occasionally I have met with a water containing traces of nitrites, which I have been compelled to conclude from the examination of the source could not be derived from sewage or manure, and which did not appear to be due to any reducing action from contact with metals. A water of this kind should only be passed as safe after a most careful examination of the source of supply has proved sewage and manure contamination to be impossible. I have also found nitrites in waters from newly constructed wells (*vide* section on this subject), apparently due to some reducing agent in the brickwork, since after a time the water yielded by these wells has been quite free therefrom. The amount of nitrite in a water is very rarely determined, as such a determination serves no useful purpose. It varies from day to day, and almost from hour to hour. A potable water which contained more nitrites than any sample I had before examined was tested by me daily. The nitrites gradually diminished, and in about a week had entirely disappeared.

There is reason to believe that nitrites are sometimes declared to be present in a water when the reaction giving this indication is really due to the presence of traces of the higher oxides of manganese. Recently the water supplied by a large Public Company was adversely reported upon by a chemist, owing to the alleged presence of nitrites. The Company's analyst found no nitrites in the water and I was called in to investigate. The springs and reservoirs were examined and a large number of samples taken. Employing one test the nitrite reaction was obtained with all, but it was particularly marked in a sample taken from a small pool adjoining one of the reservoirs and which was covered with an active confervoid growth. When these waters were filtered, only the pool water gave the reaction, and when confirmatory tests were applied it was found that the pool water alone contained nitrites. Evidently they were being formed by the reducing action of the confervoid growth on the nitrates present. A further investigation showed that the reaction first obtained (with acid and potassium iodide) was due to a trace of manganese, and that so little as one part of manganese dioxide in 40 million parts of water suffices to give the iodine reaction in a few minutes. This amount represents 1 grain of manganese in about 900 gallons of water. Upon testing the water residues, all were found to contain more than this quantity.

I obtained a little of the confervoid growth and put it in some of the Company's water and exposed it to bright sunlight, but no nitrites were found. I then added a little of Warrington's solution (solution of ammonium phosphate, &c.), and again exposed it to the sunlight. In a few hours nitrites were easily detected. There can be no doubt therefore that nitrites may occur in stored waters, which are not sewage-polluted.

It should be remembered also that nitrites are given off in smoke from burning fuel, and that traces are found in the products of the combustion of gas and in tobacco smoke. Distilled water in laboratories often contains traces of nitrites due to these causes, and I have known traces found in reservoir water attributed to the smoke from the pumping station, but I was unable to confirm this.

(*f*) **Phosphates.**—Proteid matter, whether of vegetable or animal origin, during its oxidation yields a trace of phosphates, which consequently are found in all fertile soils, but calcium phosphate being a very insoluble salt, only a minute quantity can be held in solution in a potable water. If present, they merely confirm the much more reliable and definite indications given by the nitrates and chlorides. For this reason few analysts trouble to examine for phosphates. Unless great care is taken in the analysis to decompose all silicates and remove the silica, traces of the latter may be confounded with minute traces of phosphates. This is, I suspect, the reason why some analysts detect traces of phosphates in waters in which other analysts fail to detect any. They are, no doubt, occasionally found in more than minute traces, but from a practical point of view the trouble involved in their detection is merely time wasted. Hehner suggests 0·5 part of $P_2O_5$ per million as the limit for good waters, but many excellent waters contain more than this amount. He regards its presence as evidence of pollution, but thinks that its absence does not necessarily indicate purity, since it is so readily removed from solution by iron or aluminum salts.

(*g*) **Hardness.**—For ordinary sanitary purposes it is not always necessary to estimate the amount of calcium and magnesium compounds present. It suffices usually if the soap-destroying power of these salts is determined. The soap-destroying or curdling power is of importance, as it affects the utility of the water for most domestic purposes. If excessive, it curdles soap to such an extent as to cause great waste, and it may render the water practically useless for washing purposes. For household purposes generally, a water with but little soap-destroying power is desirable, but there is no proof that such a water is better for the health of the persons using it. An excessively hard water has been accused of causing kidney disease, dyspepsia, &c., but on most unreliable evidence. A French Commission arrived at the conclusion that a moderately hard water was the best, and that persons residing in districts supplied with such water had a better physique than those living in districts where soft water was used, and a Vienna Commission expressed the same opinions. The River Pollution Commissioners, after a lengthy investigation, came to the conclusion that, 'where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water supplied to different towns, and the average rate of mortality in the different water divisions varies far less than the actual mortality in the different towns of the same division.' The late Dr. B. Ward Richardson believed that the hard waters in certain watering-places often affected the health of the visitors, causing dyspeptic symptoms. Probably this temporary indisposition is merely due to a change in the character of the water used, since I have found exactly the same series of symptoms occur in watering-places where the water is very soft, amongst the visitors who have been accustomed to the use of hard waters. The Loch Katrine water, which is very soft, is said to have caused an increased prevalence of rickets in Glasgow, but the Medical Officer of Health informs me that there is no vestige of proof that such is the case.

Hard waters deposit more or less calcium and magnesium carbonates and sulphates in kettles, pipes, and boilers in which they are boiled, and this furring causes great waste of heat and shortens the life of the utensils, and it has already been shown that for certain manufacturing and for boiler purposes hard waters are very objectionable.

The hardness due to the presence of magnesium and calcium carbonates is called 'temporary,' since, by boiling, the carbon dioxide which holds these salts in solution is driven off, and nearly the whole of the earthy carbonates is deposited. Every trace is not deposited, since neither salt is absolutely insoluble in water, and small quantities of magnesium carbonate or hydrated carbonate appear to be retained in solution by other salts contained in the water. The calcium and magnesium salts which are not deposited by boiling, such as the sulphates and chlorides, produce the hardness termed 'permanent.' A water saturated with calcium sulphate will deposit some of this salt upon boiling, since it is less soluble in hot water than in cold. If present in quantities far less than that of saturation, it is deposited when superheated under pressure, producing 'boiler scale.'

Nearly all waters possess both temporary and permanent hardness, a portion only of the earthy salts being removable by boiling. Generally speaking, the less the permanent hardness, the better is the water adapted for domestic and manufacturing purposes; and a water in which the permanent hardness is due to magnesium salts is not considered so satisfactory as one in which the hardness is due to calcium salts.

Occasionally a water may contain sufficient iron or zinc salts to appreciably affect the hardness, but the presence of considerable quantities of sodium and potassium salts appears to have only a very slight effect upon the soap-destroying power. The so-called hardness represents the soap-destroying power, and nothing more, and the attempts which have been made to deduce from the hardness information with reference to the actual quantities of calcium and magnesium salts present have introduced many fallacies and caused great confusion. There are few waters which do not contain salts of magnesium, and the soap-destroying power of these salts is much greater, weight for weight, than that of the salts of calcium, and the character of the salts and their properties have a marked effect upon the analytical results. However the soap test is applied, usually approximate results only can be obtained, since the end reaction is not always well defined, becoming more and more indefinite as the proportion of magnesium salts increases. I have ceased to attempt to determine the hardness to less than half a degree, especially as different chemists obtain results from the same water differing by two or three, or even more, degrees. This frequently occurs in the same laboratory, using the same solutions and the same water. Any attempt, therefore, to express the degrees of hardness to the first decimal place is futile. So far as I can see, it is absolutely valueless, save to the person who wishes to impart an air of pretentiousness to his results. If it is desired to obtain information with reference to the amount and character of the calcium and magnesium salts present in a water, a proper quantitative analysis should be made, instead of running the risk of drawing erroneous conclusions from the results of the soap test. Examples showing the impossibility of determining the calcium and magnesium salts by the soap test are given in a later section on the determination of the soap-destroying power of a water.

The hardness or soap-destroying power of a water is, in this country, usually expressed in degrees, each degree being equivalent to the amount of soap destroyed by one part of calcium carbonate, or rather of its equivalent in calcium chloride, in one gallon of water. The standard of 1 part in 100,000 parts of water, generally adopted in France and gradually being adopted in this country, is the one used in this work. To convert it into the grains per gallon standard, multiply by 0·7.

A water of less than 5° of hardness may be considered a very soft water, over 5° and under 10° a fairly soft water, over 10° and under 15° as neither hard nor soft, over 15° and under 20° as a moderately hard water, over 20° and under 30° a hard water, over 30° a very hard water.

When 30° is approached the water becomes very objectionable for washing purposes, but several towns in this country have public supplies of greater hardness.

An exceedingly soft water should always be examined to ascertain whether it has any action on lead, zinc, and iron, and any water with a temporary hardness below 4° should be similarly examined, as such waters usually act on these metals.

In Parliament the question is often raised as to what degree of hardness is permissible in a potable water; and in a recent Bill it was decided that a water of over 22° should be softened, more especially because several degrees of this hardness were due to magnesia salts, which Sir James Dewar contended were more detrimental to health than lime salts. In such cases private practitioners are always called who allege that they have more patients suffering from gastric derangements in the hard water districts than in the areas where a softer water is used, and the suggestion that renal calculi are more common amongst the users of hard water is generally made. There is no evidence whatever to show that moderately hard waters have any influence whatever upon health, not even when the hardness is in part due to magnesia salts; but as very hard waters for boilers, kettles, hot-water pipes, &c., cause a great loss to the community they are objectionable, and softening is advisable. Those interested in the question of the effect of hard water upon health should consult a paper by Dr. Lewis, of Folkestone, 'On the Influence of Calcareous Drinking Water in Health and Disease,' submitted to the Section of Balneology and Climatology of the Royal Society of Medicine and published in the *British Medical Journal*, July 22, 1911. His concluding sentence, however, sums up the whole matter: 'There is no evidence that hard water has any bad effect; on the contrary, all the evidence is the other way.'

In connection with this subject, the following experience may be worth recording. At a large County Asylum a water-softening plant was installed to prevent the furring of boilers and hot-water pipes. The process softened the water, but occasionally the lime was added in excess. The Medical Officer wrote to me, complaining that since the softened water had been in use there had been a marked increase in the number of inmates of the Asylum, who suffered from dyspepsia.

Still more recently Dr. Cartin, the Medical Officer to the Eastern and Western Telegraph Companies, consulted me respecting several of their stations in tropical climates where the only water available is water distilled from sea-water. At these stations Dr. Cartin finds that the teeth of their men are markedly affected. Of this, he says, there can be no doubt, and he wished some simple process devised whereby a small but uniform quantity of calcium carbonate could be introduced into the water. As the result of experiments the following process was devised for treating each 100 gallons of water distilled, this being the capacity of their distilling apparatus. To the freshly distilled water (100 gallons), 2 ounces of crystallised calcium chloride is first added and the water agitated, then 2½ ounces of sodium bicarbonate is added and the solution is stirred whilst the salt is dissolved. This results in a water containing about 5¼ grains of calcium carbonate and 6½ grains of sodium chloride per gallon, the calcium salt existing in solution as the bicarbonate. It will be interesting to ascertain whether this treatment of the water has the desired effect of preventing the dental caries which now causes so much trouble.

It is possible that during the distillation of the sea-water a little hydrochloric acid is liberated and distilled over. If such is the case the sodium bicarbonate will neutralise it with the production of a little more sodium chloride, the presence of which is probably also an advantage. A distilled water, treated in this way, appears to be more palatable than the original water.

(*h*) **Metallic Impurities (Iron, Manganese, Zinc, Lead, Copper, Arsenic).**—Natural waters containing an appreciable amount of these metals would be classed as mineral waters. Many such are known, and some are used for medicinal purposes. Potable waters are often found containing traces of iron and manganese, and occasionally zinc and lead are detected; copper I have only met with once and its presence was due to electrolytic action. Arsenic I found once in water from a well situated in a garden near a gravel path, on which an arsenical weed-killer had been used.

*Iron.*—In potable waters the iron, in probably all cases, occurs as ferrous carbonate kept in solution by an excess of carbonic acid. Upon exposure to air oxidation quickly occurs, and the water becomes more or less brown and opalescent. If more than a trace of iron is present a deposit of the oxidised product occurs. The unsightly appearance of such a water is generally sufficient to condemn it for domestic purposes. In certain localities where water has to be derived from the green-sand, this is practically the only water available, and either the unsightliness must be tolerated or some process of removing the iron adopted. If the water contains enough iron to impart the characteristic chalybeate taste, it probably could not be considered wholesome. Although I have never heard of any ill effects following the continued use of a water containing a trace of iron, I should expect headache and constipation to be produced amongst those unaccustomed to its use. For washing purposes such a water is very objectionable, as it stains the clothes, the so-called iron-mould being due to the deposition of iron oxide within the fibres of the material affected.

Water which has stood for some time in contact with iron; as in a bore pipe, may take up a minute trace of the metal, and when pumped may be turbid from the products of the oxidation of the pipe being carried forward in suspension in the water. If iron nails, for example, are placed in water the oxidising action is soon apparent, and the water becomes turbid. To prevent this action iron water mains are coated with a compound containing gas tar. It is often important to ascertain whether a trace of iron found in a water is a normal constituent or an accidental contamination. For this purpose it is necessary to obtain a sample of the water direct from its source. If this is a deep well and it is impossible to get any water save that which is derived from the bore tube, a sample should be taken after pumping has been vigorously maintained for some time, so as to remove all the water which has been standing in the tube, and as much as possible of any loosely adherent oxide. As a rule such pipes become protected by a film of rust, and in unprotected pipes this film may gradually increase in thickness until it very seriously impairs the flow of water. I have seen old four-inch mains taken up, in which the central cavity did not average more than one inch in diameter.

An exceedingly small amount of iron in a water may foster a crenothrix-like growth which causes the water to become turbid and unsightly. I have known such to occur when the iron did not exceed 0·02 part per 100,000. In this case aeration had no effect in removing the trace of iron, but filtration through Polarite proved an effectual remedy. Notwithstanding that the mains were all infected, after the installation of the Polarite filters complaints ceased, and have not recurred although the filters have now been in use for some years.

Any system of thorough aeration of a ferruginous water causes the fairly rapid precipitation of ferric oxyhydrate, but every trace of iron is not removed even if the aeration is followed by careful filtration. The addition of a little lime is believed to assist in the precipitation, but even after adding lime, aerating and filtering, a trace of iron may remain, not sufficient in itself to be objectionable, but still capable of rendering the growth of crenothrix possible. Such an infected water may remain clear in a carafe for two or more days, then suddenly become cloudy and, finally, cause a deposit on the sides of the containing vessel.

*Manganese.*—This metal is rarely tested for, but it is frequently present in minute traces, especially in waters containing iron. As it is usually present in a high state of oxidation, but not invariably, its presence is of importance, as these oxides liberate iodine from iodide of potassium, and nitrites may be declared to be present when the reaction is really due to the presence of manganese. On the Continent manganese is systematically tested for, and often found. In this country its presence is rarely detected, possibly because it is not sought for. By Continental observers also it is believed to foster the growth of crenothrix, exactly as is the case with iron, and some even regard it as more potent. So far as health is concerned, manganese is as harmless as iron, and I have never examined a sample of potable water which contained so much as to be objectionable.

*Zinc.*—This metal occurs in a few natural waters, but is usually derived from the zinc coating of galvanised iron pipes and cisterns. There is no doubt that waters, acting upon zinc and containing traces of this metal, are more common than is usually supposed, yet they may be used continuously for long periods without causing any obvious ill effects. The water supply to a small hospital with which I was connected for some years always contained a trace of zinc, probably never more than half a grain of the carbonate per gallon, but I never observed any indications of its being deleterious, although such effects were looked for. The source of the metal was a length of galvanised iron pipe which led from the water main in the road to the hospital, about a quarter of a mile away. In another instance I examined a sample of water because the medical attendant of the family using it suspected that it caused constipation, and found that it contained about three grains of zinc carbonate per gallon, derived from a galvanised iron pipe which had recently been laid to convey water from a distant spring to the house. A year afterwards the water was again examined, and found to contain large traces of the metal. The waters which exhibit this zinc solvent power may be soft or hard, but usually the temporary hardness is under 4° and the waters contain little free carbonic acid. In a recent instance in which a well-water acted upon zinc the temporary hardness was 8°, and the amount of zinc present corresponded to one grain of carbonate per gallon. A friend has communicated to me a case in which the temporary hardness was 19° and the total hardness 27°, yet the water acted on galvanised iron, the sample examined containing 0·35 part of the metal per 100,000. The water was derived from a spring and unfortunately the free $CO_2$ was not determined.

During the last few days I examined a series of water, one of which acted upon zinc. This contained 1·1 part free $CO_2$ in 100,000, whereas the others only contained 0·2 part.

All waters, especially if derived from springs, should be examined for free $CO_2$, and if more than 0·5 part per 100,000 is present the action upon zinc and other metals should be ascertained.

The amount of zinc found in water acting upon a galvanised iron pipe or cistern will depend chiefly upon the length of time the water has been in contact with the metal. The water drawn first in the morning may contain considerable quantities, whereas that drawn later in the day may contain the merest trace. Zinc is not a desirable constituent of a potable water, and in the case of a water found to act upon that metal the use of galvanised iron should be avoided. Unfortunately such waters almost invariably, if not invariably, act also upon lead, and it is therefore still more important to avoid the use of lead pipes. Tar-coated iron pipes with a very short length of iron or tin service pipe can be used. Where long service pipes of galvanised iron have been laid down the drinking water should be drawn directly from the main, and a considerable quantity always allowed to run to waste before collecting any for drinking purposes.

*Lead.*—The waters which act most energetically upon lead are those with an acid reaction derived from peaty moorlands. There are certain microbes associated with peat which are acid-producing, and impart acidity to the waters which have been in contact with the peat. Rain-water collected in the vicinity of towns has usually a slight acid reaction, and acts upon lead, the acid being derived from the products of combustion of coal. Some years ago, when investigating the effect of various manufacturing processes on the air of a country district, on the borders of Derbyshire, I found that the rain which fell to the windward of certain kilns and furnaces had a strongly acid reaction, and a marked action upon lead. The free acid was apparently sulphuric, no doubt derived from the sulphur in the coal used. In peaty waters the acid is possibly of organic origin, but I am of opinion that the acidity is nearly always due to carbonic acid. A water with an acid reaction should never be allowed to come in contact with lead.

Dr. Houston speaks of the action of neutral waters as 'erosive,' whilst that of distinctly acid waters he calls 'solvent,' and he thinks that 'the power of eroding lead is an inherent property of water containing dissolved oxygen.' 'All waters,' he says, 'do not erode lead because most of them contain substances which coat the bright surface of the metal, and so prevent any further action taking place. . . . Erosive ability *per se* is not to be regarded as an intrinsically dangerous quality of a water unless under special conditions and in the presence of bright lead.' The solvent action of a water depends upon the amount of free acid in the water, and it must be remembered that this varies very considerably from time to time. The extent of this variation can only be ascertained by examining a considerable number of samples at different seasons.

I have made hundreds of experiments to ascertain the conditions under which waters act upon lead, and the only conclusive results, so far obtained, are that no water acts upon this metal unless both carbon dioxide and oxygen are present in it; and it seems probable that when the $CO_2$ is in a certain excess a solvent action is exerted, whereas when oxygen is in excess the action is erosive. Unfortunately I have not yet been able to tabulate and consider fully all the results obtained.

When acid waters have to be used for public supplies, it is now becoming usual to pass them through beds of chalk or limestone to neutralise the acidity. This does not in all cases entirely prevent the plumbo-solvent action, as a trace of carbonates in solution is not sufficient to prevent the action of a water upon lead. Where the carbonate is that of calcium or magnesium, about 4 parts per 100,000 are required before the action on lead entirely ceases.

Hard waters from the Bagshot beds frequently exhibit a marked erosive power, since the hardness is almost entirely of a permanent character. On the other hand, certain very soft waters which act powerfully on both tarnished and untarnished lead are supplying large communities, Glasgow and Manchester for example, without producing any evil effect. Professor W. A. Miller, F.R.S., considers that such waters, when passed through a pipe continuously, paint, as it were, the inside with a deposit of vegetable matter, which combines with the oxide of lead and so forms a closely adherent film, which prevents all action.

Others think they cause the inner surface of the pipe to become coated with a film of an oxycarbonate of lead more insoluble than the metal itself, and that when this is once formed all action of the water upon the lead ceases. These waters, however, have no markedly acid reaction like those which, derived from peaty moorlands, have had such a deleterious effect upon the inhabitants of certain towns in Lancashire and Yorkshire. In these towns lead-poisoning was prevalent for a considerable period, doing immense damage to the health of the inhabitants, before its real nature was recognised and its cause discovered. Dr. Hunter, describing the effects at Pudsey, says: 'Anæmia and debility were the most common symptoms. The debility was peculiar; the patients nearly always complained that they felt as if they would sink down from weakness, and that the least exertion would make them sweat freely. . . . The majority of the people had the blue gum line so characteristic of lead-poisoning. Colic also was a common symptom. Paralysis was not common, but we had five or six cases of what might almost be called general paralysis, so helpless were the patients, and in these cases drop-wrist was included.' Other effects produced are depression, melancholia, and actual insanity, constipation and indigestion, gout, kidney disease, and blindness. Still-births increase in number, and the children of lead-poisoned persons are rickety and ill-developed.

The amount of lead found in the waters producing the above effects varied from one-hundredth to one grain or more per gallon, the larger amount being found in the water drawn in the early morning after standing overnight in the lead service pipes. As lead is a cumulative poison, and persons vary in degree of susceptibility to its action, some being more susceptible than others, it follows that the use of water containing the slightest trace of this metal is fraught with danger. I have investigated cases of plumbism where the lead was derived from the lead suction pipe to the pumps, the whole of the water in the wells being contaminated. It is therefore very important, when examining a water, to determine its action upon lead whenever the temporary hardness is found to be under 4°. If any action takes place the users should be warned of the danger of using lead pipes, or lead cisterns, in any portion of the service. The so-called block-tin pipes often contain lead, and have repeatedly been found to impart a trace of that metal to water allowed to stand therein.

*Copper.*—I have only examined one sample of water containing copper. This I attributed to electrolytic action. A sample was sent to me for analysis on account of its supposed action on copper tubing. This water contained a rather large amount of chlorides, but I failed to discover anything to account for the alleged action.

*Arsenic.*—Many natural waters are known which contain traces of this poison, but it is never sought for in an ordinary analysis. Tests would only be applied when making a complete analysis, or when some illness causes suspicion to rest upon the water of containing an irritant poison. The slightest trace would naturally condemn any water for domestic purposes.

*Barium.*—A very minute trace of this metal occurs in some Derbyshire springs, never sufficient, however, to have any significance.

(*i*) *Other Constituents.*—Upon occasion the question arises whether certain saline constituents are likely to have any effect upon health. Certain of these have already been referred to, but quite recently I have had to express opinions upon two waters containing unusual quantities of magnesium and sodium sulphate. These waters are common in Essex, and though a well yielding such a water may be used for a time it is often abandoned on account of its laxative effect. Occasionally also animals have been affected. In the first case sodium sulphate was present to the extent of 60 to 70 grains of the crystalline salt per gallon of water. It was the only constituent in the water which might be objectionable and it seemed practically impossible to obtain any other supply. The question therefore was simply whether the amount of this salt imbibed would have any effect upon the health of the children. Assuming that each child drank three pints daily, about 25 grains would be taken into the system. The dose given in 'Squire's Companion' to the British Pharmacopœia is '30 to 120 grains for repeated administration, for a single administration ¼ to ½ an ounce.' About a minimum dose therefore was being taken daily. The same authority also states: 'In small repeated doses it is especially well adapted for cases of constipation associated with gout and hepatic dyspepsia.' The evidence of the Medical Officer to the Institution was to the effect that it had been used for years and that he had no reason to regard it as unwholesome. During the many years he had attended the scholars he had never suspected the water as being the cause of any derangement. Under these circumstances I saw no reason for expressing an adverse opinion upon the water.

In the second case a water containing magnesium sulphate equivalent to 42 grains of the crystallised salt, and sodium sulphate equivalent to 42 grains of the B.P. sulphate, in each gallon, was proposed to be used for the purposes of a public supply to a town in the tropics. Considering the amount which might be imbibed daily under tropical conditions, and the prevalence of choleraic diseases in the locality, I expressed the opinion that it was not a suitable water for domestic purposes. Its hardness and salinity (it contained also some 30 grains of salt per gallon) rendered it quite unsuitable for boiler and manufacturing purposes.

The question of the effect of sodium carbonate with or without a comparatively small amount of sodium sulphate is assuming considerable importance in consequence of the introduction of the ' Permutit ' system of water softening. A large Water Company, thinking of adopting this process, desired me to consider the question so far as it related to their water supply, and I reported that the softened water would be perfectly wholesome. Since then I have had to consider the question with reference to other waters, and the following is a copy of one of my reports thereon:

'I have made a considerable number of experiments with Permutit, using hard waters from various sources, and have made analyses of the waters before and after softening. The results show that all the lime and magnesia salts are removed and soda salts substituted, that is to say, that the hard waters containing carbonates and sulphates of lime and magnesia become converted into soft waters containing no salts of lime or magnesia, but amounts of carbonate and sulphate of soda corresponding to the lime and magnesia salts removed.

'Assuming that a water had 30° of hardness, a very excessive amount, and that it has passed through Permutit, the hardness will have entirely disappeared and the water will then contain about 25 to 30 grains of carbonate of soda per gallon. The question therefore is whether this amount of soda salts will affect the health of those who drink the water.

'Fortunately I am in an exceptional position for giving an opinion upon the point as waters containing considerable quantities of soda salts are used for public supplies in many towns in the county for which I am Medical Officer of Health, and I have recently been able to prove that these waters[1] are derived from very hard chalk waters which have undergone nature's softening process, and that nature's process is exactly the same as that of Permutit. The Thanet sands under Essex and London contain a small quantity of a mineral allied to Permutit, and when very hard waters are slowly passed through they become softened. A cubic foot of Permutit, however, will soften many gallons of water in a few minutes, whereas it would take a cubic yard of Thanet sand many hours to produce the same softening effect. As these soft waters are used by about 100,000 people in this county I am able to give an opinion based upon actual experience extending over twenty years, and that opinion is that these softened waters are perfectly wholesome, as wholesome as any other water occurring in nature.

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[1] *The Lancet*, February 3, 1912.

'I have just completed the analyses of all the public water supplies in the county of Essex, and from the quantities of carbonate and sulphate of soda present in the soft waters I have calculated the original hardness of the waters from which they are obtained. These are given in the following Table, and I have also added the average death-rate for the districts for the past ten years.

| Name of Waterworks | Population supplied | Death rate for last 10 years | In grains per gallon | | Total | Estimated hardness of original water |
|---|---|---|---|---|---|---|
| | | | Sodium carbonate | Sodium sulphate | | |
| Gt. Baddow . | 5000 | 12 (*abt.*) | 24·0 | 5·7 | 29·7 | 26·7 |
| Benfleet . . | 7500 | 12·6 | 18·8 | 6·5 | 25·3 | 23·0 |
| Braintree . . | 5330 | 15·0 | 14·0 | 8·5 | 22·5 | 19·4 |
| Wyvenhoe . . | 3000 | 9·3 | 12·6 | 9·9 | 22·5 | 19·6 |
| Burnham . . | 3200 | 11·7 | 23·9 | 6·6 | 30·5 | 27·3 |
| Maldon . . | 5700 | 14·4 | 26·0 | 6·4 | 32·4 | 30 |
| Witham . . | 3640 | 12·0 | 18·7 | 7·6 | 26·3 | 22·8 |
| Broomfield (Works approved by L.G.B., but not yet completed) | | | 25·0 | 5·8 | 30·8 | 28·3 |
| Southend . . | 70,000 | 12·0 | 19·6 | 7·0 | 26·6 | 24·5 |
| Heybridge . . | 2000 (*abt.*) | | 21·7 | 9·1 | 30.8 | 28 |
| Chelmsford (partial supply) . . | | 13·3 | 24·8 | 7·0 | 31·8 | 28·7 |
| Writtle . . | 2000 (*abt.*) | 13 (*abt.*) | 22·8 | 9·5 | 32·3 | 29·0 |

**Average death-rate for the whole county for the past 10 years = 13·1.**

'During the twenty years I have had these districts under observation, there has never been the slightest reason to suspect that any of the above public water supplies were of anything but the most wholesome character. In many parts of the county we have small local supplies containing much more of the soda salts and they are equally wholesome. The most popular Table Waters in the world are waters which contain larger quantities of the above soda salts, and a large proportion of the members of the medical profession regard them as more suitable for drinking purposes than ordinary hard waters.

'Natural seltzer-water contains about 58 grains of carbonate of soda per gallon.

'Natural Apollinaris water contains about the same quantity.

'A natural water bottled at Peterborough contains about 40 grains of carbonate and 12¼ grains of sulphate of soda, and is very highly spoken of by *The Lancet* (February, 1904) in whose laboratory the analysis was made.

'There can be no question therefore that waters softened by the Permutit process are perfectly wholesome, assuming, of course, that the waters originally were free from polluting matters of a dangerous character.'

(*j*) **Free Ammonia.**—Very few natural waters are found which do not contain some trace of ammonium salts. Except in acid rain and moorland water, it probably always exists as ammonium carbonate. By the distillation of such waters, with or without the addition of a little alkali, the ammonia is carried over in the distillate and is spoken of as 'free' ammonia, to distinguish it from a further quantity of ammonia, which can be obtained by adding a strong alkaline solution of potassium permanganate to the concentrated water, and continuing the distillation. This latter quantity is spoken of as the 'albuminoid' ammonia, a term which is misleading, since this ammonia does not exist in the water, but is produced by the decomposition of the nitrogenous organic matter by the alkaline permanganate.

To understand the significance of the free ammonia and of the quantity present, it is necessary to consider the various sources from which it may be derived. Rain and snow always contain a trace, the first fall containing most. The amount varies very considerably, from 0·01 to 0·2 part per 100,000, but is usually about 0·06.

All fertile soils and all decaying vegetable and animal matter contain ammonia, yet rain falling upon manured ground may reach the subsoil water practically free from it, the nitrifying organisms having converted it into nitrates. Urine of men and animals yields large quantities of ammonium carbonate by fermentation, hence sewage is rich in ammonia. Nitrates by their reduction yield ammonia, consequently a water containing nitrates which has been subject to the reducing action of ferruginous sands, or of long lengths of metal pipes, may contain it.

Certain low forms of vegetable life, e.g. Crenothrix, produce ammonia in the water they infect, but whether produced during life or only by their death and decay is not yet determined.

Dr. Munro, in his studies on nitrification, observes that a large quantity of ammonia 'may disappear in a few days with a corresponding increase of nitrate; this is specially liable to occur in summer, and should a week elapse between the analyses of the same sample of water some very striking differences in the results would be manifest, although each analysis might be perfectly correct.' With reference to the presence in water of ammonia derived from other sources than manure or sewage he says: 'Ammonia may be present in the stagnant waters supporting confervoid growths, as a bye-product of the reduction of nitrate by various organisms.' He adds, however, 'Ammonia formed by reduction is not of frequent occurrence in well waters, unless it is accompanied by ammonia resulting from putrefaction.'

It is obvious, therefore, that the ammonia found in water may be derived from harmless sources, or from sources indicating serious pollution. Without knowing from what it is derived, it is perfectly impossible to say whether it indicates serious contamination or not. The waters yielding most free ammonia come from the Thanet sands and chalk in certain parts of the London Basin, waters which are free from more than a minute trace of organic matter, and certainly free from the slightest suspicion of sewage pollution. Yet I have seen analysts' reports arguing that such large quantities of ammonia could only be derived from urine, and condemning the waters as sewage-polluted.

The amount of ammonia found in the water from a deep well may vary enormously from time to time, and I strongly suspect that the most of this is due, in many cases, to the reduction of the nitrates existing in the water by the metal of the bore pipes. This is confirmed by certain experiments made some time ago, when I found that the water first pumped from one of these deep wells contained a very large amount of ammonia, whereas that taken later in the day was nearly ammonia-free.

A nitrated water filtered through a layer of sand from the lower London tertiaries becomes highly charged with ammonia, and apparently the reduction is due to the ferrous aluminate present in these sands. Every sample of such sand which I have examined possessed the power of reducing nitrates.

It is often difficult, if not impossible, to judge of the character of a water by the amount of ammonia which it contains, but wherever the amount exceeds 0·004 part per 100,000 an endeavour should be made to ascertain its origin. Considered together with the amount yielded by the organic matter present, correct inferences can usually be drawn. Rain-waters collected from roofs may not only contain ammonia derived from the air, but a further quantity derived from the bird droppings, soot, and decaying vegetable matter which collects on housetops, in spouts, &c. Anything in excess of 0·01 per 100,000 occurring in a water containing an excess of organic matter almost certainly indicates sewage pollution, but upland surface waters being directly derived from the rainfall may contain 0·01 part without being polluted, and moorland surface water, especially if peaty, may contain the same amount associated with more organic matter and yet be pure. Subsoil and spring waters should contain very little ammonia, if soil purification has been efficient. It is rare that a really satisfactory water contains more than 0·006 part per 100,000. Deep well-waters can only be judged from a knowledge of the amounts usually found in waters from the particular strata from which they are derived, and as such waters should contain an exceedingly minute trace of organic matter, if an excess of both ammonia and organic matter is found, pollution should be suspected. The Essex deep wells above referred to, which yield waters containing very variable and often very excessive amounts of ammonia when uncontaminated, contain very little or no organic matter. Pure river waters rarely contain more than 0·004 part per 100,000, and any excess is probably due to sewage or drainage from manured land.

From the above observations it will be gathered that no correct inference can be drawn from the results of an estimation of the ammonia only. A water containing much ammonia may be free from manurial or sewage matter, whilst a water containing only a very small quantity may be polluted. Considered together with the amount of ammonia yielded by the organic matter present in the water, by distillation with a strongly alkaline solution of potassium permanganate, valuable information is obtainable, often enabling us at once to detect sewage pollution, though rarely justifying us in pronouncing a water free from any trace of sewage or manurial contamination.

Even the very small quantity which is generally regarded as permissible may be derived directly from sewage, as will be shown in the next section; hence the great importance of possessing an intimate knowledge of the source of a water before attempting to interpret the significance of the amount of ammonia obtained therefrom.

(*k*) **Organic Matter.**—Leaving out of question for the present the living organisms, bacteria, &c., and any dead organic matter which may be suspended in the water and which would be subject to bacterioscopic or microscopic examination, the organic matter in solution must be of vegetable or animal origin. Practically the whole of this must have been derived from the lichens and low forms of vegetable life on rocks, mosses and peat on moorlands, the humus of fertile soil, excrement of animals, manurial matters, and possibly sewage. Decaying vegetation in streams, lakes, ponds and reservoirs may contribute to the organic matter. Whatever its source there is a natural tendency for it to disappear, the carbon being converted into carbonic acid, and the nitrogen into nitric acid, but in nearly every case a residuum remains which is apparently not easily fermentable or putrescible. 'The soil,' to quote Dr. Munro, 'is the abode of many ferments, some of them having opposed functions, but all lying in wait for suitable conditions which shall encourage one species for a little while until it has done its work and has brought about an alteration favourable in turn to the encouragement of another species. From the soil, these ferments pass into the waters, from which they are not completely removed even by filtration, and the nitric ferment, certainly one of the most subtle of them all, seems little affected by this process. The addition of any ordinary organic matter instantly excites activity in one or other of these ferments, and the effect is soon visible to the eye by the impaired clearness of the water, and to chemical tests by the effect produced on the nitrate of the water.'

'The organic matter of potable waters can only be such organic matter as is unfermentable, or at any rate not rapidly or easily fermentable. . . . What two compounds, for example, could exhibit a greater contrast than gelatine and potassium thiocyanate? Yet the one is as readily broken down by soil ferments as the other.'

As all waters at some time in their history must have been in contact with organic matter, and as this organic matter speedily undergoes change, leaving a certain residuum not easily oxidised, it is obvious that an analysis may often afford very little information of any value. If pollution has been recent, some of the more readily oxidisable matter may remain in the water and be detectable, but even then we may not be able to decide whether this is of vegetable or animal origin.

By no known process can the amount of organic matter in solution in potable water be estimated with any approach to accuracy. The difficulty of the problem is obvious when we reflect that very few such waters contain as much as half a grain of organic matter in the gallon. It is very doubtful whether this organic matter is ever of such a quality as to have any effect upon health, even if it is derived from sewage or manure. Hence an accurate determination of the quantity present would serve no practical purpose, as it is not so much the quantity as the quality which is of importance from the diagnostic point of view. As the quantity of organic matter is too small in most potable waters to be in itself a source of danger, whatever the quality, it might appear unnecessary to attempt either a qualitative or a quantitative analysis; but such is not the case, since from certain determinations information can be obtained which has a value in throwing some light on the source from which the organic matter is derived, and as indicating to a certain extent the amount of organic pollution.

As organic matter of vegetable origin is of little significance, most of the tests applied in the analysis of water are for the purpose of attempting to differentiate between it and animal contamination. Some tests, while not professing to differentiate between the two, indicate whether the water contains any readily oxidisable matter or not. One such test consists in ascertaining what amount of oxygen the water is capable of taking up from an acid solution of potassium permanganate. Occasionally substances of mineral origin, the lower oxides of iron, nitrites and hydric sulphide, are present capable of absorbing oxygen from this salt, in which case it is necessary to first ascertain as approximately as possible how much is taken up by these substances; the remainder may then be attributed to the organic matter.

The following Table was devised by the late Sir E. Frankland and Dr. Tidy, and the standards given have been generally adopted.

Amount of Oxygen absorbed in 100,000 Parts of Water

| | Upland surface Water | Other Waters |
|---|---|---|
| Waters of great organic purity. | Not more than ·10 | Not more than ·05 |
| Waters of medium purity . | ,, ,, ·30 | ,, ,, ·15 |
| Waters of doubtful purity . | ,, ,, ·40 | ,, ,, ·20 |
| Impure water . . . . | More than ·40 | More than ·20 |

The amount of risk involved in using a water, unfortunately, does not always vary with the amount of oxidisable organic matter present; but if an excess is present, and especially if other results indicating contamination are high, the water must be considered as more or less unsatisfactory. One of the oldest and most difficult methods of examining the organic constituents of a potable water was devised by the late Sir E. Frankland, F.R.S., and is still used in a few laboratories. By this method the amount of carbon and nitrogen in the organic matter present in a water residue is determined, and from the results obtained inferences as to the extent and character of the pollution are drawn. The process is a eudiometric one, requiring a specially equipped laboratory and great care in manipulation, and even when conducted by those experienced in its use the errors of experiment are considerable. It possesses no advantage whatever over simpler methods, and, no doubt, it will shortly only be remembered in chemical histories. Those who wish to learn more about this process may consult Frankland's 'Water Analysis.'

Many other processes have been devised by chemists for approximately estimating the organic matter in water or for ascertaining its character. Attempts have been made to devise processes for detecting certain definite compounds such as cystin, the presence of which should indicate sewage contamination. None of these have ever been generally used, and there is no doubt that while most of them were utterly useless, others were certainly misleading. The most generally useful information concerning the soluble organic matter in water can be obtained by the process, first devised by Professor Wanklyn, for estimating the so-called 'albuminoid' ammonia.

Some clue to the nature or origin of the organic matter may possibly be found by this process. It gives no definite indication as to the actual amount of organic matter present, since some bodies yield all their nitrogen as ammonia, and others only an aliquot part. Albuminoid substances of animal origin contain about 17 per cent. of nitrogen, and some readily yield the whole in the form of ammonia, whilst others do not. Vegetable matters usually contain a much smaller proportion of nitrogen; hence the amount of albuminoid ammonia obtained upon the analysis of water is no indication of the actual amount of the organic substances present, and it is often impossible to say whether it is derived from a small amount of animal matter or a larger amount of vegetable matter.

It is usual to consider the free ammonia and albuminoid ammonia together, as their relative proportion is really more important than the actual quantities. The reason for this is that in all sewages and nearly all sewage effluents the amount of free ammonia greatly exceeds that of the albuminoid ammonia. This is well shown in the following examples :

In Parts per 100,000

| — | Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|---|
| B. H. crude sewage . . . . | 0·00 | 5·9 | 2·2 | 5·9 |
| A good effluent . . . . | 2·9 | 1·5 | 0·05 | 1·01 |

In the crude sewage the free ammonia is two and a half times as great as the albuminoid ammonia, whilst in the effluent it is thirty times as great. Hence in most cases when a water yields more free ammonia than albuminoid ammonia, the indications are that the water is more or less polluted with sewage.

Decaying vegetable matter in a water yields more albuminoid ammonia than free ammonia. For example, an infusion of dead leaves and a peaty water gave the following results on analysis :

Parts per 100,000

| — | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| Infusion of leaves . . . | ·003 | ·031 | ·814 |
| Peaty water . . . . | ·001 | ·024 | ·19 |

Peaty water, to which has been added one per cent. of the sewage and one per cent. of the sewage effluent just referred to, would have given the following results respectively :

| Peaty water with | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 1 per cent. sewage . . . . | 0·60 | ·046 | ·249 |
| 1 per cent. sewage effluent . . . | 0·16 | ·024 | ·20 |

These results would indicate sewage pollution in each case, decided in the first and less definite in the second, since the free ammonia even in the second is far in excess of what is usually found in peaty waters.

Another sewage effluent recently examined by me, which contained thousands of the Bacillus coli communis and other sewage organisms per c.c., gave the following results :

| Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 4·44 | ·052 | ·096 | ·79 |

A mixture of this with 99 per cent. of distilled water gives a water which would be classed amongst those of the highest organic purity. One per cent. added to the tap water in my laboratory gave :

| Nitric nitrogen | Free ammonia | Albuminoid ammonia | Oxygen absorbed |
|---|---|---|---|
| 1·04 | ·001 | ·002 | ·04 |

This analysis gives no indication whatever of sewage pollution, yet the water contained one per cent. of effluent, and a bacteriological examination revealed the presence of sewage organisms in abundance.

Water yielding over 0·01 part per 100,000 of albuminoid ammonia, if associated with free ammonia to the extent of 0·006, must be looked upon with grave suspicion. If the free ammonia reaches or exceeds 0·008 and there is no indication of its being derived from a harmless source, recent sewage pollution is strongly to be suspected. When the free ammonia is low and the albuminoid ammonia comparatively high, as in the case of peaty water, vegetable contamination is indicated, especially if the water yields this albuminoid ammonia slowly.

The whole of the organic nitrogen may be determined by Kjeldahl's process. This, though less troublesome than the eudiometric method, yet occupies more time and requires greater care than the estimation of the albuminoid ammonia. No doubt it would be more scientific to estimate the whole of the nitrogen than a part. The chemists to the Massachusetts State Board of Health[1] say that 'the albuminoid ammonia, as determined in our usual practice, is, in amount, about one-half of the ammonia which the total organic matter would be capable of yielding.' Notwithstanding this, they add: 'The determination of albuminoid ammonia does not in itself convey any information as to the character of the organic matter in water. Standards of purity based simply on the amount of albuminoid ammonia are of little or no value, since it is the quality of organic matter rather than its quantity that immediately concerns us.' Obviously, therefore, if the nitrogen bears such a definite relation to the albuminoid ammonia as they suggest, the determination of the nitrogen has no greater value than the estimation of the albuminoid ammonia. The general opinion, however, is that the nitrogen in the albuminoid ammonia bears no constant relation to the total nitrogen. Whether such is the case or not, no more definite conclusions can be drawn from the total nitrogen determination than from that of the albuminoid ammonia, and hence the simpler process continues to be generally adopted.

Sewage is a most complex mixture of excremental matters and other filth, dissolved and suspended in water. There is no one constituent which the chemist can detect in water which can be said with certainty to indicate the presence of sewage. Pollution, recent or remote, is inferred if an excessive amount of chlorides, nitrates, phosphates, ammonia, and organic matter is found in the water. But nearly all these substances may be derived from other and perfectly harmless sources, and, as we have seen, a small amount of sewage may be present without increasing to any appreciable extent the amount of any of these constituents. Waters classed by the most eminent analysts as pure and wholesome have caused serious outbreaks of typhoid fever; whilst other waters, condemned on account of the presence of an excess of one or more of the compounds just mentioned, are used with absolute impunity. This chiefly arises from the fact that by no chemical process can it be determined whether the small amount of organic matter found in nearly all waters is of vegetable or animal origin. The organic constituents of sewage or manure may have undergone as complete oxidation as would ensue by perfect combustion in a furnace, whereby only the innocuous mineral matter remains to indicate that the water ever was polluted. If this oxidation has also been so fully supplemented by natural filtration that all the organisms present in the original polluting matter have been removed (but whether this is the case or not can only be ascertained by a bacteriological examination), the water must be considered of satisfactory quality.

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[1] State Board of Health, Massachusetts, 1890: *Examination of Water Supplies*, p. 545.

In new wells constructed of brickwork on wooden curbs, the wood continues to impart a trace of organic matter to the water; the bricks also affect the water, the result being that waters from such wells are often condemned, whereas after a time they yield water of a satisfactory quality. This subject is of such importance that I purpose dealing with it in a later portion of this section.

The necessity of acknowledging the limitations of the knowledge obtainable from the chemical analysis of a water is my excuse for further emphasising it by reference to other experiments, made to ascertain to what extent the results of an analysis can be relied upon.

In the following experiments the water used was derived from the water mains in Chelmsford Borough. With this was made a 1 per cent. infusion of tea, and various quantities of this filtered infusion were added to one litre of tap water. A sample of the town sewage was obtained, and portions of this were added to another litre of water. The analytical results were as under, and show that the addition of tea infusion rendered the water more impure chemically than the corresponding quantities of sewage, and that whilst the 0·1 per cent. sewage-polluted water would have been passed as chemically of the highest degree of organic purity, the water containing a corresponding quantity of tea infusion would be regarded as of doubtful quality:

In Parts per 100,000

| — | Chlorine | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| Tap water, ·1 per cent. sewage . . | 16·0 | ·003 | ·0005 | ·0291 |
| Tap water, ·1 per cent. tea infusion . | 15·9 | ·0005 | ·0120 | ·190 |

The bacteriological results were very different. The Bacillus coli communis could be detected in 1 c.c. of the sewage-polluted water, and the Bacillus enteritidis sporogenes in 25 c.c.

Using a larger proportion of sewage and tea infusion, the chemical results were still unsatisfactory.

In Parts per 100,000

| — | Chlorine | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| Tap water, ·5 per cent. sewage . . | 16·3 | ·008 | ·005 | ·080 |
| Tap water, ·5 per cent. tea infusion . | 15·9 | ·003 | ·032 | ·940 |

By bacteriological examination the Bacillus enteritidis could be demonstrated in 5 c.c. of the sewage-polluted water.

I have frequently met with waters which, upon chemical examination, appeared to be polluted, although the sources from which they were derived were found to be practically free from any possibility of contamination. On the other hand, I have occasionally found waters of the highest degree of organic purity, which came from sources I felt bound to condemn on account of the possibility of pollution. Doubtless, when such waters are examined at regular intervals by bacteriological methods, sooner or later indications of pollution are found. As an instance, I may record the case of a public water supply derived from the chalk formation. I regarded the source as being unsatisfactory for two reasons. In the first place, there were numerous cesspits and farmyards on the collecting area besides other sources of contamination, and in the second there was danger of infiltration from a sewage-polluted river near. Yet, in about forty examinations the organic matter had always been so low as to cause the water to be classed amongst those of the highest degree of organic purity. Bacteriologically the results were generally satisfactory, but after a recent spell of wet weather I was able to detect both the Bacillus coli and the Bacillus enteritidis in a sample. This sample gave the following results on analysis, showing that chemically it was of a very high degree of purity.

| Chlorine | Nitric nitrogen | Free ammonia | Organic ammonia | Oxygen absorbed |
|---|---|---|---|---|
| 1·05 | 12·9 | ·000 | ·002 | ·022 |

Other instances of a similar character will be referred to later.

At the instigation of the Local Government Board,[1] Drs. Klein and Houston recently conducted an investigation 'in order more accurately to determine in regard to water the relative value of chemical and bacterioscopic analysis simultaneously conducted—to ascertain, that is, to what extent severally chemical and bacterioscopic examination of waters purposely sewage-polluted can yield definite indications of contamination. For analysing the experimentally polluted waters two processes were chosen, which are in general use among chemists at the present day.

'Ammonia process (Wanklyn). 500 c.c. of the polluted water were examined in the ordinary way for free and albuminoid ammonia.

'Oxygen permanganate process (Tidy, Frankland, and others). 500 c.c. of the polluted water were dealt with, and the experiments were carried out at a temperature of 100° C. The chemical results are shown on Table I.

'In each case, 1,000 c.c. of sterile distilled water were polluted with a definite quantity of crude sewage. Of the contaminated water 500 c.c. were used for the ammonia process and 500 c.c. for the oxygen permanganate process. In experiments 1, 2, 3, 4, the samples of sewage were obtained from a single source, and in experiment 5 from a second source, and in experiments 6, 7, 8, from a third source. In experiment 9 a natural water, known to be polluted with sewage, was selected for examination :

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[1] Report of the Medical Officer of Health. Local Government Board, 1898–9.

TABLE I.—SHOWING THE RESULTS OF THE CHEMICAL EXAMINATION OF DISTILLED WATER POLLUTED WITH VARYING AMOUNTS OF CRUDE SEWAGE

PARTS PER 100,000

| Exp. distilled water polluted with | Oxygen absorbed from permanganate in 1 hour at 100°C. | Free ammonia | Organic ammonia |
|---|---|---|---|
| 1. 1 per cent. crude sewage, dilution 1 in 100 . . . | ·3138 | ·0864 | ·0224 |
| 2. ·1 per cent. crude sewage, dilution 1 in 1,000 . . . | ·0848 | ·004 | ·001 |
| 3. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | ·0018 | ·0000 | ·0004 |
| 4. ·005 per cent. crude sewage, dilution 1 in 20,000 . . . | nil | nil | nil |
| 5. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | No record | ·003 | ·0026 |
| 6. 1·0 per cent. crude sewage, dilution 1 in 100 . . . | ·1375 | ·0213 | ·0062 |
| 7. ·1 per cent. crude sewage, dilution 1 in 1,000 . . . | ·0326 | ·0021 | ·0006 |
| 8. ·01 per cent. crude sewage, dilution 1 in 10,000 . . . | ·0119 | ? trace | ·0012 |
| 9. Thames water below Staines . | ·4648 | ·0054 | ·031 |

'In considering from the chemical point of view the results recorded in Table I., it is to be noted that,

'Judged by the oxygen-absorbed process at 100° C., experiment 1 denotes a water of medium purity, experiment 9 a water of suspicious organic purity. The rest of the experiments denote waters varying from medium purity to great organic purity, and that,

'Judged by the ammonia process, experiments 1 and 9 denote dirty waters, experiments 2, 3, 4, 5, 7, 8, waters of great purity, while experiment 6 denotes a water organically safe.

'It must be remembered, however, that most natural waters contain more than mere traces of organic matter. Indeed, many of them contain an amount which is not far short of placing them in the class of waters of doubtful purity. Hence additional pollution in the above way might bring them from the class of water of great purity into the class of waters which are of medium purity, or from the class of waters of medium purity into that which includes waters to be regarded with suspicion or even condemned.'

In all the above waters the bacterioscopic analysis showed the presence of both the Bacillus coli and the Bacillus enteritidis sporogenes. It is obvious therefore that no water can be said to be absolutely free from sewage pollution as the result of chemical analysis. If the detection of such traces of pollution is the object of the investigation, a bacteriological examination is imperative.

(*l*) **American views** on the interpretation of the results of chemical analysis.

The following remarks on the Interpretation of Water Analysis are taken from the Report of the Massachusetts State Board of Health,[1] and show that the results of their large experience coincide with those obtained in this country:

'In classifying waters from a sanitary standpoint, the most obvious and useful distinction is into waters which are polluted either directly or indirectly with sewage, or in general with the waste products of human life and industry, and those which are free from such contamination. The latter class of waters we will call "normal." Normal waters may differ widely in character from the pure, colourless, mountain stream to the brown water of swamps; but they have this in common, that they have never received any contamination connected with the life of man. It is not meant to be implied in this distinction that normal waters are necessarily good to drink, but they are never capable of producing those specific troubles which have their origin in disordered vital processes.

'The chemical analysis alone may sometimes fail to distinguish a normal from a sewage-contaminated surface water. In the Table on p. 148 are grouped together the results of the analyses of several normal and polluted waters, which have been selected to show that in some cases not only is no single determination conclusive as regards the origin and quality of a water, but that all the determinations taken together do not always suffice to give us the information we desire.

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[1] 1890. *The Examination of Water Supplies*, Chapter II., Section 3.

'Thus among the polluted waters are found some in which the albuminoid ammonia is lower than in the waters which are unpolluted. The same is also true of the free ammonia, the nitrates, nitrites, chlorine, &c. Again, the great variation in the amounts of these substances, even among the normal waters, shows that we have to deal with facts that do not necessarily carry their interpretation with them. But in all these cases a knowledge of the location and environment of these waters renders the results of the analyses intelligible, as we shall see later on.

'The presence of organic matter, or ammonia, and even a bad odour in a well water, does not necessarily imply that the ground water of the region is polluted. The trouble may be in the well itself, which may contain organic matter which has dropped in from the surface—insects, worms, and the like. In some wells the water at the bottom is stagnant. The water does not become bad on this account unless organic matter gets access to it, when putrefactive changes set in, owing to insufficient supply of dissolved oxygen, and the water becomes very foul. The remedy in such cases is very simple, namely, cleaning the well and protecting it carefully at the surface.

'At the beginning of this discussion we have spoken of the doubtful value of standards of purity of water based on the amount of the nitrogen compounds which it contains. In the case of ground waters there is an ideal standard of purity which is at the same time not an impossible one, namely, complete freedom from unoxidised or partly oxidised compounds of nitrogen. We do not know, as has been already explained, that a water which reaches this standard is safe if at the same time it contains much nitrogen completely oxidised, but we do know that as we depart from this standard we enter the region of known danger. It has been a very general custom hitherto to set limits for each of the substances beyond which the water should be regarded as polluted or as unfit for drinking.

'The application of these standards of purity made the interpretation of analyses a very simple matter, but of very doubtful value. It has been thought worth while in the above discussion to show, in much detail, the one-sided and faulty deductions

## TABLE OF ANALYSES OF NORMAL AND POLLUTED SURFACE WATERS

(*Massachusetts Report*, 1890, *page* 541)

| No. | Appearance | | | Residue on evaporation | | | Ammonia | | Chlorine | Nitrogen as | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Turbidity | Sediment | Colour | Total | Loss on ignition | Fixed | Free | Albuminoid | | Nitrates | Nitrites |
| NORMAL WATERS (PARTS PER 100,000) | | | | | | | | | | | |
| 1 | None | Very slight | 0·00 | 5·00 | 0·70 | 4·30 | ·0000 | ·0022 | 0·08 | ·0060 | ·0000 |
| 2 | Decided | Heavy | 0·10 | 2·50 | 0·95 | 1·55 | ·0000 | ·0702 | 0·10 | ·0030 | ·0006 |
| 3 | Decided | Slight | 0·60 | 5·15 | 3·25 | 1·90 | ·0000 | ·1252 | 0·11 | ·0000 | ·0000 |
| 4 | Slight | Slight | 0·40 | 3·65 | 1·65 | 2·00 | ·0130 | ·0333 | 0·16 | ·0250 | ·0001 |
| 5 | Slight | None | 0·30 | 3·25 | 0·95 | 2·30 | ·0000 | ·0136 | 0·63 | ·0050 | ·0000 |
| 6 | Slight | None | 0·00 | 5·95 | 0·80 | 5·15 | ·0000 | ·0152 | 2·10 | ·0060 | ·0001 |
| POLLUTED WATERS | | | | | | | | | | | |
| 1 | Distinct | Considerable | 0·10 | 10·75 | 2·05 | 8·70 | ·0124 | ·0284 | 0·19 | ·0150 | ·0009 |
| 2 | Very slight | Very slight | 0·55 | 5·15 | 1·95 | 3·20 | ·0000 | ·0196 | 0·54 | ·0550 | ·0004 |
| 3 | Distinct | Slight | 0·10 | 5·00 | 0·85 | 4·15 | ·0016 | ·0198 | 0·58 | ·0200 | ·0004 |
| 4 | Slight | Slight | 0·15 | 10·25 | 1·20 | 9·05 | ·0000 | ·0262 | 2·09 | ·0170 | ·0010 |
| 5 | Slight | Slight | 0·15 | 12·70 | 2·10 | 10·60 | ·0664 | ·0263 | 2·41 | ·0800 | ·0025 |

which may be made by giving too much weight to any one determination. Thus we have said that free ammonia is the evidence of decomposition of nitrogenous organic matter already begun, that it is the characteristic ingredient of sewage, that it is one of the most reliable indications of sewage pollution in water. And yet under certain conditions we have seen that a sewage-polluted water may be free from ammonia and that a normal water may contain it abundantly.

'Two lessons are to be learnt from this (and they cannot be too strongly emphasised), namely, first, that a single determination in a chemical analysis of a water cannot tell us what the real condition of the water is; and, second, that one complete analysis tells us only what was the condition of the water when the sample was taken.

'A single analysis, for instance, may be selected from the monthly examinations of Mystic Lake, which will show the water to be in a very good condition, with only the presence of the chlorine to indicate past pollution. Yet a glance at the series of analyses will show that this condition is unusual, and that the water contains, for the greater part of the year, products of decomposition of organic matter in considerable amount. Such facts do not detract from the value of the chemical analysis of waters, but show rather how easily a fatal mistake may be made by trusting to incomplete and infrequent analyses.

'The recorded and well-authenticated cases of illness resulting from drinking ground water are very numerous—far greater in number than those which can with certainty be referred to the use of waters of streams and lakes. Investigation of these cases shows almost invariably that the water of the well has received directly, or indirectly through the soil, the drainage of houses or cesspools. All wells in the vicinity of houses or barns are more or less exposed to such contamination, and it is a matter of the first importance to know how far the information derived from a chemical analysis will enable us to say whether or not a well water can be used with safety. If we regarded the organic matter, or the products of its decay, as the sole cause of danger, then we should have in the determination of the nitrogen compounds a perfectly satisfactory means of deciding whether the water is in a fit condition to use. From this point of view we should reject all waters which contained free or albuminoid ammonia or nitrites, and accept only those which contained all the nitrogen in the form of nitrates.

'But if the danger is to be ascribed to the presence of bacteria in the water, the results of a chemical analysis offer, as in the case of surface waters, only indirect evidence of its condition.

'Where normal ground waters are not to be had, safety lies in time and distance from the source of pollution—the greater these are, the greater the security from harm. Waters with very high nitrates are always to be regarded with suspicion, even though they show for a long period a good purification, for high nitrates indicate a nearness of the source of pollution which is a constant menace to the purity of the water. Where the margin of safety is small a slight change in the existing conditions may result in a sudden and serious pollution of the well. Moreover, from the standpoint of bacterial contamination we cannot feel secure, even when the chemical purification is practically complete, if the source of contamination is near.'

(*m*) **French Standards.**—The French Consultative Committee of Hygiene has submitted a Table of Standards which is generally adopted in France. Its utility is very limited, and an unreasoning adoption of it would lead to serious errors. It is given here for what it is worth :

PARTS PER 100,000

| — | Pure waters | Potable waters | Suspicious waters | Bad waters |
|---|---|---|---|---|
| Nitric nitrogen . | ·00 | ·00 to ·10 | ·4 to ·8 | Over ·8 |
| Free ammonia . | ·000 to ·005 | ·005 to ·010 | ·010 to ·015 | Over ·015 |
| Albuminoid ammonia | ·000 to ·005 | ·000 to ·005<br>(·005 to ·010[1]) | ·005 to ·010<br>(·010 to ·015[1]) | Over ·015 |
| Oxygen absorbed . | Under ·10 | ·10 to ·20 | ·30 to ·40 | Over ·40 |
| Chlorine . . | Under 1·5 | 1·5 to 4·0 | 5·0 to 10·0 | Over 10·0 |
| Hardness . . | 5° to 15° | 15° to 30° | Over 30° | Over 100° |

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[1] These figures to be taken if there is little or no free ammonia present.

(*n*) **Table of Analyses.**—As I possess records of the sources of a large number of samples of water examined in my laboratories, a number of these have been selected and tabulated so that it is easy to compare the conclusions arrived at from the examination of the source and from the chemical analysis of the water (*vide* pp. 152–3). In every case the source of supply was examined by myself either when the sample was taken or soon afterwards. It will be found that whilst many agree with the above standards for pure and bad waters, few agree with the intervening standard. A water is either 'safe' for use for domestic purposes or is 'unsafe,' and when the source is examined it is rarely necessary to use the terms 'doubtful' or 'suspicious.'

(*o*) **Water from New Wells.**—In rural districts no newly erected house can be inhabited until a certificate is obtained from the Sanitary Authority to the effect that it has within a reasonable distance an available supply of wholesome water sufficient for all domestic purposes. The usual source of supply is a shallow well. These wells are rarely properly constructed, and the necessary certificate should be withheld until the well is made to the satisfaction of the Medical Officer of Health. When completed it should be examined, and if necessary a sample of water taken for analysis. This analysis will tell whether the water is too hard or contains an excessive amount of saline matter, but very often it has led to the well being condemned because the water contained too large a trace of organic matter, erroneously attributed to sewage or manurial matter. This has so often occurred when sewage or manurial contamination was practically impossible that some explanation was needed, and my late assistant, Dr. Dunlop, now Medical Officer of Health for the Borough of Torquay, carried out an investigation in my laboratory to ascertain the cause. The fact was previously well known, and had been attributed to workmen micturating in or near the well during construction, to dirt getting in from their boots, &c. On several occasions, when the water in a new well did not improve, a cause has been found on examination. I have discovered old

### ANALYSES OF WATERS FROM VARIOUS SOURCES. (Results in Parts per 100,000.)

| No. | Source | Possibilities of contamination | Chlorine | Nitric and nitrous nitrogen | Nitrites | Hardness | Free ammonia | Albuminoid ammonia | Oxygen absorbed | Bacteriological results | Reported |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shallow well | Serious from farmyard | 18·3 | 3·0 | ·0 | 34° | ·002 | ·006 | ·026 | — | Unsafe |
| 2 | Subsoil | None, town supply | 2·6 | 1·4 | ·0 | 12° | ·002 | ·003 | ·019 | Good | Safe |
| 3 | As 2 | Quarter mile galv. iron pipe [1] | 2·6 | 1·2 | ·0 | 12° | ·024 | ·003 | ·145 | — | Zinc-contaminated |
| 4 | Shallow well | Farmyard (?) | ·5 | ·7 | ·0 | 40° | ·000 | ·004 | ·036 | — | Safe |
| 5 | Shallow well, new | None | 3·2 | ·25 | *t.* | 41° | ·064 | ·016 | ·300 | — | Safe |
| 6 | Spring | From ditch cont. sewage | 8·0 | ·9 | ·0 | 6° | ·002 | ·016 | — | — | Unsafe |
| 7 | Same as 6 | After rain | 3·4 | — | ·0 | 9° | ·018 | ·120 | — | — | Unsafe |
| 8 | New well | None apparent | 8·6 | 1·0 | *t.* | 23° | ·008 | ·020 | — | — | Safe |
| 9 | Same as 8 | 4 months later [2] | 3·9 | 1·0 | *t.* | 15° | ·024 | ·014 | — | — | Examine well |
| 10 | Same as 8 | After cleaning | 2·6 | 1·2 | ·0 | 9° | ·000 | ·012 | ·015 | — | Safe |
| 11 | Shallow well | None | 4·0 | ·07 | ·0 | 39° | ·016 | ·007 | — | — | Safe |
| 12 | Subsoil, P.S. | Long length galv. iron pipe | 3·4 | ·8 | *l.t.* | 10° | ·132 | ·006 | ·34 | Good | Contains zinc |
| 13 | Shallow well | None [3] | 2·3 | ·6 | *l.t.* | 8°·5 | ·018 | ·010 | — | Found crenothrix | Unsatisfactory |
| 14 | Same as 13 | Before crenothrix infection | 1·9 | ·6 | ·0 | 11° | ·000 | ·012 | — | — | Safe |
| 15 | Shallow well | Sewage from blocked drain dropping in [4] | 18·0 | 1·3 | *m.t.* | 31° | ·004 | ·006 | ·103 | — | Unsafe |
| 16 | Shallow well, new | Carefully selected site, bored | 10·7 | ·1 | *t.* | 17° | ·020 | ·024 | — | — | Safe |
| 17 | Shallow well, boulder clay | None, odour of $H_2S$ [5] | 2·8 | ·0 | ·0 | 30° | ·016 | ·008 | ·202 | — | Unsatisfactory |
| 18 | Deep well | None | 23·6 | ·14 | ·0 | 5° | ·019 | ·005 | ·080 | Good | Safe |
| 19 | Shallow well, new | None | 2·9 | ·98 | ·0 | 24° | ·018 | ·005 | ·128 | — | Safe |
| 20 | Well near 19 | None | 1·9 | ·83 | *m.t.* | 14° | ·002 | ·005 | ·020 | — | Safe |
| 21 | Deep well | None | 37·1 | ·2 | ·0 | 7° | ·016 | ·004 | — | Good | Safe |
| 22 | P. spring | A sewer near [6] | 4·0 | — | ·0 | — | *t.* | ·0042 | ·022 | — | Unsafe |
| 23 | Same as 22 | After heavy rain | 4·1 | ·2 | ·0 | 20° | ·030 | ·028 | ·175 | Sewage organisms | Polluted |
| 24 | Deep well | Defective near top, ditch near [7] | 38·6 | ·17 | ·0 | 7° | ·002 | ·004 | ·100 | — | Unsafe |
| 25 | New tube well | None | 9·7 | 1·2 | *t.* | 24° | ·064 | ·010 | ·09 | — | Large trace iron, safe |
| 26 | Deep well | Farmyard | 40·1 | ·43 | *t.* | 4° | ·020 | ·004 | ·108 | — | Unsafe |
| 27 | Deep well | Urinal near [8] | 33· | ·09 | ·0 | 4° | ·012 | ·012 | ·09 | — | Unsafe |
| 28 | Same as 27 | None | 33· | ·04 | ·0 | 7° | ·006 | ·005 | ·12 | — | Safe |
| 29 | Deep well | Top defective, dirty ditch very near | 50·8 | ·10 | ·0 | 6° | ·068 | ·008 | ·12 | — | Unsafe |
| 30 | As 29 | After a flood | 54·3 | ·48 | ·0 | 9° | ·052 | ·012 | — | — | Polluted |
| 31 | Spring | In ditch, seriously liable to pollution | 3·0 | 1·8 | ·0 | 11° | ·000 | ·012 | — | — | Unsafe |
| 32 | Spring | In ditch, seriously liable to pollution | 4·6 | ·6 | ·0 | 10° | ·005 | ·006 | 0·28 | — | Unsafe |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | Spring . . . | Carefully protected, supplying village . . . . . | 4·0 | ·54 | ·0 | 19° | ·012 | ·008 | ·155 | — | Good |
| 34 | Surface water . | A town supply, moorland[9] . . | ·9 | ·18 | ·0 | 10° | ·002 | ·013 | ·262 | No sewage organisms | Unsatisfactory |
| 35 | Spring . . | At edge of hop plantation, inefficiently protected[10] . . . | 3·3 | 1·4 | ·0 | 19° | ·000 | ·0005 | ·016 | — | Dangerous |
| 36 | Shallow well . | None . . . . . . . | 1·7 | ·2 | ·0 | 16° | ·001 | ·009 | — | — | Safe |
| 37 | Same as 36 . . | Water had acquired a curious odour[11] . . . . . | 1·7 | ·1 | ·0 | 16° | ·000 | ·008 | — | — | Unsatisfactory |
| 38 | Deep well . . | None . . . . . . . | 3·7 | ·04 | ·0 | 31° | ·020 | ·003 | ·038 | — | Safe |
| 39 | Trial bore, 7 ft. . | None[12]. . . . . . . | 420· | ·17 | ·0 | 36° | ·012 | ·038 | — | — | Unfit for use |
| 40 | Trial bore, 7 ft. . | Close to No. 39 . . . . | 15·9 | ·2 | ·0 | 32° | ·001 | ·014 | — | — | Safe |
| 41 | Spring . . . | Well protected . . . | 2·3 | 1·0 | ·0 | 7° | ·002 | ·006 | ·038 | Good | Safe |
| 42 | House tap . . | Same as 41[13] . . . . . | 3·0 | ·9 | *l.t.* | 14° | ·068 | ·004 | ·600 | — | Much zinc |
| 43 | Spring . . . | None, a town's supply[14] . . | 4·0 | 1·2 | ·0 | 16° | ·008 | ·005 | ·044 | Good | Safe |
| 44 | Chalk well . | Cesspools, &c.[15] . . . . . | 3·7 | ·4 | *l.t.* | 19° | ·056 | ·014 | ·213 | — | Unsafe |
| 45 | Deep well . . | Top imperfect, polluted subsoil . | 62·0 | ·2 | ·0 | 9° | ·105 | ·005 | ·039 | — | Unsafe |
| 46 | Same as 45 . . | Showing subsoil pollution[16] . | 31·4 | 3·6 | *t.* | 24° | ·002 | ·020 | — | — | Polluted |

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[1] This water contained about 1 part of zinc per 100,000.

[2] This well when opened was found to contain some old ropes and sacking left behind by the workmen.

[3] This water had a disagreeable odour and contained a trace of iron.

[4] Not being able to account for the presence of the nitrites, I had the well opened, when the source of pollution was discovered.

[5] There was no possibility of sewage pollution in this case. As the water did not improve in character, the well was abandoned.

[6] This is the only analysis included which was not made in my laboratory. The chemist who made it certified that it was good and could not possibly be the cause of the typhoid fever which was raging amongst those who used it. I had regarded it as unsafe without an analysis, because it became turbid after rain. Later I examined a sample taken when the water was in a turbid condition with the result shown in No. 23.

[7] This water I regarded as unsafe because of its becoming turbid after rain. Shortly afterwards a case of typhoid fever occurred in the house supplied from this source, and when the well was opened traces of filth were found on the side nearest a ditch receiving sewage. The polluting matter only entered when a rainfall filled the ditch.

[8] From a public well. Corner near used by lads as a urinal. The corner was closed in and the water in the well pumped to waste. When the water again rose it gave the results recorded in No. 28.

[9] This water swarmed with Volvox globator.

[10] The spring water alleged to have caused the Maidstone epidemic. Taken while the epidemic was raging.

[11] This water was from a new well and had a very curious and decided odour. When the well was opened a sack of shavings was found in it.

[12] Water from a trial bore in superficial gravel in the centre of Essex. The source of the chlorides was never discovered. (*Vide* No. 40.)

[13] This water was condemned as sewage-polluted by an analyst of repute. He did not detect the presence of zinc. I examined the spring water (41) and the water after it reached the house through a length of galvanised iron piping with the above results.

[14] This water contained a minute trace of zinc. An analyst who had examined a sample taken from the same house with a new supply pipe of galvanised iron found a little more free ammonia and certified that the water was contaminated with sewage. Legal proceedings followed, and I was able to prove that the water was above suspicion of pollution.

[15] This well supplies a large population. When pumping is going on the water-level is depressed for a considerable distance around, and there are many cesspools within the area of depression. I regard the source as unsafe.

[16] The well yielding the waters Nos. 45 and 46 is near a churchyard and in the centre of a very insanitary village. The section showed 15 feet of gravel and 100 or more feet of London clay, the water coming from the Thanet sands. The upper part of the well was undoubtedly defective, and there were obvious signs of sub-soil water entering. At a later period when the subsoil had become charged with water I again examined the water from the well with the results recorded. It will be nóted that the polluting subsoil water had decreased the amount of chlorides and of free ammonia, but increased the nitrates, hardness, and organic ammonia.

rope, sacks, bits of wood, vegetable debris, &c., at the bottom of such wells.

As illustrations of the improvement in the character of water from new wells, Dr. Dunlop gave the following examples :

| Source | Date of analysis | Chlorine | Free ammonia | Albuminoid ammonia |
|---|---|---|---|---|
| New shallow well . . | 5–7–1893 | 19·3 | ·006 | ·006 |
| Same well . . . . | 1–12–1893 | 3·8 | ·001 | ·002 |
| New shallow well . . | 10–7–1895 | 3·4 | ·100 | ·028 |
| Same well . . . . | 27–11–1895 | 3·4 | ·005 | ·014 |
| Deep well . . . . | –3–1891 | 20·0 | ·100 | ·032 |
| Same well . . . . | –6–1891 | 32·1 | ·048 | ·005 |
| Same well . . . . | –9–1891 | 32·7 | ·001 | ·0015 |

The deep well was particularly interesting, as I knew that it had been constructed by a firm of the highest standing. Subsoil water had gained access to the bore during construction, and had apparently had a marked effect in lowering the chlorine in the water. It was six months before the water became quite normal. No doubt it would have improved much earlier had any large quantity been taken from the well, but the amount used was very limited. Dr. Dunlop took samples of the materials actually used in the construction of a well, rejecting however a sample of cement which had been made with road scrapings, and after digesting these in water recorded the results. These were as under :

| Description of sample | Chlorine | Free ammonia | Albuminoid ammonia | Nitrites |
|---|---|---|---|---|
| Tap water used in experiments . | 16·0 | ·000 | ·004 | ·00 |
| Tap water digested with portion of elm curb . . . . . . | 16·0 | ·200 | ·100 | ·00 |
| Tap water digested with deal curb . | 17·9 | ·009 | ·030 | ·00 |
| Tap water with cement . . . | 16·0 | ·025 | ·032 | ·00 |
| Tap water with brick . . . | 16·0 | ·002 | ·016 | Trace |

The increase in the amount of chlorides in the infusion of deal led to further experiments showing that certain samples of this wood contain a considerable amount of salt: doubtless the original logs had floated for some time in salt water.

The brickwork appears to be responsible for the trace of nitrites often found in water from new wells. Dr. Dunlop concludes that 'the temporary pollution of wells sunk in clean soil is almost wholly due to the action of the water on the materials employed in the construction of the wells. This accounts for the great change for the better which such waters often undergo in a few weeks.'

One of the most important uses of chemical analyses is the determining of the character of the well and spring water supplies upon which so large a proportion of the rural community depend. Medical Officers of Health have frequently to decide whether a village requires a public water supply or not, and if water is fairly abundant, it is sometimes a difficult matter to convince a Sanitary Authority that a better water supply is necessary. As I am frequently asked what should be done in such a case I append a report, prepared some time ago, relating to a village in Essex, and which convinced the Authorities that a public water supply was needed. It will be noted that chemical analyses alone are quoted. The bacteriological results were found to be absolutely unnecessary, and they were confusing.

## REPORT OF THE WATER SUPPLY TO THE PARISH OF W—— IN THE CHELMSFORD RURAL DISTRICT.

The parish of W—— has an area of 7397 acres and a population of 2462. At the census taken in 1881 the population was 2412. The rateable value is £12,882. By far the largest portion of the population resides in the village and in its extension towards the west, called, Oxney Green. I estimate the population of the village with Oxney Green at about 1400, and it is to the water supply of these portions of the parish that this report refers.

The village stands on a patch of gravel which at the extreme end of Oxney Green is covered with a layer of brick earth. The gravel rests upon the London clay, which here is about 300 feet thick. The gravel varies in thickness from about 60 feet on the highest part of Oxney Green to about 8 or 10 feet in the lowest part of the village near the river. The water-level varies much. Thus in Chequers Lane it is 4½ to 9 feet only from the surface, whilst at Baker's cottages, about 200 yards away, and at approximately the same elevation, it is 45 feet from the surface. At Miss Dickson's cottages, about midway between the two, it is 16 feet. Lower down the Green, at Hitch's cottages, it is 54 feet. From this point, however, it gradually becomes nearer the surface, being only 11 feet below at the public pump and about 9 feet in the wells at the lowest portion of the village. The level of the ground water falls in the direction of the two streams, one running from west to east, the other from south to north, at the outskirt of the village. At Oxney Green the wells yield a very limited supply in summer, not nearly sufficient in quantity for the requirements of the population. In the village the supply is abundant, but, as we shall see, the quality in nearly every instance leaves much to be desired. Though there is a good fall for a sewer down Oxney Green, the water available for flushing purposes would probably be very inadequate. The wells on Oxney Green are some distance apart, and some supply as many as twelve to fourteen cottages. About the middle of the Green there is a bored well, just off the roadside, and the Sanitary Authority charges a rent of 1*s.* per quarter on all the cottages using the water which is raised by a wheel pump. The water from this well is exceedingly soft and pure, but unfortunately the supply is only sufficient for the houses in the immediate vicinity. Many cottages have recently been erected in this portion of the parish, and others are in course of erection. As only one new well has been sunk for several years past, the water supply is becoming each year more scanty and the necessity for a public supply more urgent.

A few of the better houses in the village have water-closets; most of the others have pail-closets, which are emptied periodically by the public scavenger, but there are still many midden privies and cesspits, and as the drainage is very defective and the ground very porous, the subsoil has become seriously polluted and its effect can be traced in the waters of nearly all the wells.

During the past two months I have examined samples of water from every known well in W—— village and Oxney Green. The analytical results are embodied in the Table on pp. 160–1. The numbers in the first column indicate the position of the wells on the map of the village.[1] Besides the samples of well water, I have examined several from the springs at the margin of the gravel patch upon which Writtle village stands, and also from the springs on the north of Oxney Green, fed by a patch of gravel upon which there are only two farms and very few cottages. The analyses of these waters give a standard with which those used in the village can be compared. In the following comparison the water from the wheel pump is not included, its source and character being entirely different from all the others.

In the spring waters the total solid matter in each gallon varies from about 28 to 32 grains and the hardness from about 20 to 26 degrees. None of the village waters contain less than 30 grains of total solids per gallon, few less than 40 grains, whilst many contain from 90 grains upwards. As for hardness, many of the well waters compare favourably with the spring waters, but the average degree of hardness of the well waters is much above that of the springs. In the latter also nearly the whole of the hardness is temporary, that is, it is removable by simply boiling, whereas in the former the permanent hardness, not removable by boiling, is often very excessive.

Filthy matters percolating from defective privies, cesspools, drains, &c., into the ground, may, under certain circumstances, enter a well either unchanged or in but a slightly changed condition. Such may arise where the upper portion of the wells are not properly constructed and rendered impervious, and where defective drains, cesspits, &c., exist very near to them. These conditions exist in very many parts of the district we are considering, and the presence of the filth is shown by the excessive amount of organic ammonia yielded and the quantity of oxygen absorbed by the waters from many of the wells. On the other hand, much of the filthy matter may become oxidised and possibly rendered innocuous by having to filter through a considerable thickness of 'living earth' before it reaches the wells. In such cases we do not find any great excess of organic matter in the water, but we still find the chlorine derived from the salt in the urine, and we find an excess of nitrates (the product of the oxidation of the excretory and other filthy matters) proportionate to the amount of filth which has undergone oxidation and change. Whilst the pure spring waters contain only from 1 to 1½ grains of chlorine per gallon, but a few of the well waters contain less than 3 grains, whilst nearly half of them contain 8 or more grains. The amount of nitrates varies even to as large an extent. In the spring waters we find from a quarter to half a grain of nitric nitrogen (1 grain of this nitrogen corresponds to 4½ grains of nitric acid or 7·2 grains of nitrate of potash or saltpetre, the combination in which it is probably present in the water), whilst only four of the village supplies contain less than half a grain, the majority of them containing from 1 to 3 grains, whilst many exceed even this latter amount. It is evident, therefore, that nearly all the wells show the presence of water derived from the filthiest and most dangerous sources, which has become more or less purified by filtration through the soil. Nearly all contain this purified sewage, whilst some of them are no better than the effluent from a well-conducted sewage farm.

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[1] This map is not reproduced. The wells extend in nearly a straight line from the highest point in the parish (1) to the lowest (50) near the river.

Waters of this character are especially dangerous. They are liable to vary in composition almost from day to day. A heavy rain may cause the water falling on the ground to wash the filth through the soil more rapidly than it can be purified, and the polluted water so gains access to the wells.

The well from which sample No. 11 was taken was sunk within the last few years on ground which has not become sewage-sodden. After rain, however, the water becomes turbid, proving that impurities can be washed into the well, and that the water occasionally becomes polluted. 16[1] (*a*) and (*b*) are from the same well. Hockley's pump is of lead ; Dent's of iron. The water from the latter pump contained a trace of iron, and the nitrites and ammonia are due to the action of the metal on the nitrates present. Sample 22 (*a*) was taken from the well during dry weather ; sample 22 (*b*) was taken a few days later, after a heavy rain. The difference was most marked.

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[1] I have since found that pumps No. 17 and 18 also draw from one well.

Of the fifty samples from different sources in the village, about nine contain so little oxidised sewage matter (as measured by the nitric nitrogen and chlorine) and so little organic matter (as measured by the free and organic ammonia and oxygen absorbed) that one might fairly infer that the risk of unchanged sewage matters gaining access to the wells is comparatively small, but with such a porous subsoil as that at W—— it is impossible to say that this risk is so small as to be negligible. All the other waters must be considered unsafe ; some of them are very filthy and totally unfit for any household use.

Almost without exception the waters are very hard, causing a great waste of soap when used for washing purposes. The permanent hardness of some causes them to be objectionable from a medical point of view, since such waters are believed to give rise to many forms of indigestion.

There is only one public pump in the village, and fortunately this yields one of the best waters.

The conclusion at which I have arrived is that a public supply of pure water is urgently required for the village—a supply sufficiently abundant to allow of the water being laid on to every house and cottage, and being used not only for ordinary domestic purposes, but also for supplying baths and water-closets. Over and above this, there should be sufficient for thoroughly flushing every portion of the sewerage system when the new sewers are laid down.

Such a supply would also enable the Sanitary Authority to abolish all the privies, which at present are a constant cause of nuisance and source of danger.

In referring to the report I stated that bacteriological results were not quoted, because they sometimes contradicted the

## WRITTLE WATER SUPPLY

### Results of Analyses made by Dr. Thresh, Medical Officer of Health

| No. on Plan | Physical Characters | In Grains per Gallon |  |  |  |  |  |  |  | In Parts per Million |  |  | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Total Solids | Effect of Ignition | Nitric Nitrogen | Nitrites | Chlorine | Temporary Hardness | Total Hardness | Permanent Hardness | Free Ammonia | Organic Ammonia | Oxygen used in 4 hours |  |
| 1 | Clear, ft. yellow | 101· | F. char. | 3·82 | v. m. t. | 8·2 | 18·° | 32· | 14· | ·01 | ·14 | 1·50 | Much oxidised sewage |
| 2 | „ „ | 80· | „ | 2·37 | ·0 | 9·6 | 23·° | 26· | 3· | ·00 | ·12 | 1·60 | „ „ |
| 3 | „ „ | 92· | Char. | 3·45 | t. | 7·1 | 21·5 | 31· | 9·5 | ·00 | ·22 | 2·23 | „ „ |
| 4 | „ „ | 95· | „ | 2·23 | l. t. | 9·7 | 23· | 31· | 8· | ·32 | ·28 | 2·75 | „ „ |
| 5 | „ „ | 70· | F. char. | 2·10 | ·0 | 8·0 | 22·5 | 26· | 3·5 | ·02 | ·12 | 1·35 | „ „ |
| 6 | „ „ | 69· | Char. | 1·61 | ·0 | 7·7 | 22·5 | 25·5 | 3· | ·00 | ·12 | ·87 |  |
| 7 | „ yellow tint | 85· | F. char. | 2·10 | ·0 | 8·8 | 25·5 | 33·3 | 7·5 | ·00 | ·12 | 1·10 |  |
| 8 | „ ft. yellow | 45· | „ | 1·49 | ·0 | 3·6 | 18·5 | 23· | 4·5 | ·00 | ·06 | ·52 |  |
| 9 | „ „ | 60· | Char. | 1·23 | ·0 | 6·3 | 18·5 | 23·5 | 5· | ·02 | ·04 | ·70 |  |
| 10 | „ „ | 71·5 | F. char. | 3·90 | ·0 | 5·6 | 23· | 27· | 4· | 2· about | ·11 | 1·10 | „ „ |
| 11 | „ „ | 59· | „ | ·52[1] | ·0 | 5·8 | 23· | 29· | 6· | ·00 | ·06 | ·50 |  |
| 12 | „ „ | 63· | „ | 1·24 | ·0 | 7·7 | 22· | 23· | 1· | ·01 | ·08 | ·40 |  |
| 13 | „ „ | 67· | „ | 1·43 | ·0 | 9·0 | 20· | 23· | 3· | ·03 | ·07 | ·68 |  |
| 14 | Ft. turbid, ft. yellow | 74· | „ | 1·25 | ·0 | 10·6 | 25· | 28· | 3· | ·00 | ·05 | ·65 |  |
| 15 | „ „ | 74· | „ | 1·23 | ·0 | 10·4 | 25·5 | 27· | 1·5 | ·00 | ·05 | ·72 |  |
| 16 (a) | Clear and colourless | 66· | Nil | 2·47 | ·0 | 4·6 | 22· | 22· | — | ·00 | ·04 | ·52 | „ „ |
| 16 (b) | Ft. turbid and yellow | 73· | St. char. | 2·50 | l. t. | 4·9 | 22· | 27· | 5· | ·08 | ·05 | 1·60 | „ „ |
| 17 | Clear and colourless | 109· | Nil | 3·97 | ·0 | 11·0 | 25· | 36· | 11· | ·04 | ·05 | ·78 | „ „ |
| 18 | Ft. turbid and yellow | 110· | „ | 3·98 | ·0 | 11·2 | 24· | 37· | 13· | ·04 | ·05 | ·40 | „ „ |
| 19 | „ „ | 101· | St. char. | 3·09 | ·0 | 8·7 | 19· | 34· | 15· | ·02 | ·12 | 1·65 | „ „ |
| 20 | Clear and colourless | 118· | „ | 4·22 | t. | 13·7 | 25·5 | 38· | 12·5 | ·06 | ·09 | ·80 | „ „ |
| 21 | „ „ | 104· | Nil | 3·45 | ·0 | 10·6 | 21·5 | 42· | 20·5 | ·02 | ·05 | 1·01 | „ „ |
| 22 (a) | Ft. turbid and yellow | 144· | Ft. char. | 9·10 | ·0 | 14·9 | 27·7 | 58· | 30·3 | ·12 | ·12 | ·90 | „ „ |
| 22 (b) | „ vile odour | 160· | „ | 6·87 | ·0 | 14·1 | 23·0 | 39· | 16· | ·06 | ·20 | 1·29 | „ „ |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | Ft. turbid and yellow | 94· | „ | 1·13 | ·0 | 10·9 | 25· | 38· | 13· | ·08 | ·10 | ·94 | „ „ |
| 24 | „ „ | 122· | Char. | 1·86 | t. | 18·4 | 32· | 43· | 13· | ·02 | ·18 | 2·90 | „ „ |
| 25 | „ „ | 130· | Became yellow | 4·65 | ·0 | 11·3 | 22·5 | 40·5 | 18· | ·00 | ·12 | 1·56 | „ „ |
| 26 | „ „ | 50· | St. char. | ·71 | ·0 | 4·75 | 19· | 24· | 5· | ·02 | ·08 | ·80 | Usable. |
| 27 | Very turbid, vile odour | 53· | Char. | 1·76 | t. | 4·4 | 14· | 18· | 4· | 4· about | ·84 | 8·87 | Putrid sewage. |
| 28 | Clear and ft. yellow | 46· | Ft. char. | ·94 | ·0 | 3·5 | 15· | 19· | 4· | ·01 | ·09 | ·73 | Usable. |
| 29 | „ „ | 44· | Nil | ·54 | ·0 | 2·7 | 15· | 19· | 4· | ·01 | ·02 | ·23 | Good. |
| 30 | „ „ | 49· | Ft. char. | ·92 | ·0 | 3·9 | 15· | 19· | 4· | ·00 | ·05 | ·55 | Usable. |
| 31 | „ „ | 62· | „ | 1·85 | ·0 | 5·7 | 14·25 | 25· | 10·75 | ·04 | ·12 | 1·125 | Much oxidised sewage. |
| 32 | „ „ | 32· | „ | ·45 | ·0 | 2·3 | 15·75 | 18· | ·25 | ·00 | ·05 | ·875 | Good. |
| 33 | „ yellow | 100· | Char. | 2·72 | ·0 | 8·2 | 19· | 30· | 11· | ·28 | ·20 | 2·30 | Much polluted. |
| 34 | Ft. turbid and yellow | 63· | „ | ·91 | ·0 | 8·05 | (45·)[2] | 23·5 | — | 2· about | ·32 | 3·95 | Sewage. |
| 35 | Clear and colourless | 35· | Nil | ·84 | ·0 | 2·6 | 15· | 24· | 9· | ·04 | ·03 | ·37 | Good. |
| 36 | „ „ | 44· | „ | ·65 | ·0 | 4·1 | 19·25 | 25· | 5·75 | ·00 | ·02 | ·47 | Good. |
| 37 | „ „ | 45· | „ | 1·04 | v. m. t. | 3·8 | 15·25 | 23· | 7·75 | ·02 | ·02 | ·45 | From same well. |
| 38 | „ „ | 38· | „ | ·65 | ·0 | 3·3 | 19· | 20· | 1· | ·03 | ·025 | ·69 | Variable. Unsafe. |
| 39 | „ „ | 34· | „ | 1·00 | ·0 | 2·8 | 16· | 19· | 3· | ·00 | ·02 | ·43 | Usable. |
| 40 | „ „ | 37· | „ | ·31 | ·0 | 2·6 | 19· | 21· | 2· | ·00 | ·01 | ·13 | Good. |
| 41 | Very faintly turbid | 70· | V. ft. char. | ·125 | v. m. t. | 17·4 | (23·5)[3] | 3·5 | — | ·00 | ·02 | ·50 | „ |
| 42 | Faintly turbid | 78· | St. char. | 3·72 | „ | 8·9 | 14·5 | 37· | 12·5 | ·08 | ·10 | ·58 | Much oxidised sewage. |
| 43 | Clear and colourless | 38· | Nil | ·35 | ·0 | 3·2 | 15·5 | 18· | 5· | ·02 | ·05 | ·44 | Good. |
| 44 | Ft. turbid and yellow | 54· | „ | 1·85 | ·0 | 2·6 | 16·0 | 26· | 10· | ·00 | ·02 | ·55 | Doubtful. |
| 45 | „ „ | 51· | Ft. char. | 1·25 | ·0 | 2·6 | 16·75 | 24· | 7·25 | ·00 | ·05 | ·23 | „ |
| 46 | Clear and colourless | 37· | V. ft. char. | ·07 | ·0 | 2·8 | 20·5 | 23· | 2·5 | ·00 | ·02 | ·59 | Good. |
| 47 | „ „ | 56· | Nil | 1·33 | m. t. | 3·6 | 11·5 | 25· | 13·5 | ·02 | ·05 | 1·00 | Doubtful. |
| 48 | „ „ | 45· | „ | 1·05 | v. m. t. | 3·7 | 17·6 | 31· | 13·4 | ·05 | ·04 | ·60 | „ |
| 49 | „ | 43· | „ | ·56 | ·0 | 3·3 | 17·4 | 28· | 10·6 | ·00 | ·01 | ·35 | Good, but very hard. |
| 50 | „ „ | 31· | „ | 2·00 | ·0 | 2·3 | 3·0 | 12·5 | 9·5 | ·01 | ·02 | ·10 | Much oxidised sewage. |
| | Clear and colourless | 31·5 | Ft. char. | ·42 | ·0 | 1·54 | 18·3 | 22· | 3·7 | ·00 | ·03 | ·34 | Good. |
| | „ „ | 31· | Nil | ·25 | ·0 | 1·12 | 20·3 | 26· | 5·7 | ·00 | ·00 | ·29 | „ |
| | „ „ | 28· | Ft. char. | ·45 | ·0 | 1·05 | 14·4 | 20· | 5·6 | ·07 | ·06 | ·875 | „ |
| | „ „ | 29· | Nil | ·25 | ·0 | 1·90 | 19· | 22· | 3· | ·02 | ·03 | ·025 | „ |
| | „ „ | 28· | „ | ·33 | ·0 | 1·50 | 16·5 | 20· | 3·5 | ·01 | ·02 | ·025 | „ |

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[1] This water becomes turbid after rain and is therefore unsafe.

[2] Temporary hardness measured by Alkalinity. In this case the Alkalinity is not entirely due to Carbonate of Lime.

[3] Alkalinity due to Carbonate of Sodium.

conclusion arrived at, from a consideration of the chemical analyses. Unfortunately this not infrequently occurs; hence where only one or the other examination has to be made I usually prefer a chemical analysis, but with a water the source of which is not perfectly well known both a chemical and bacteriological examination are necessary if an opinion of any value is to be given. As illustration, the following recent experiences may be quoted. In the first a sample of water was submitted to me from a well at a farm, at which there was a case of typhoid fever. The water was clean and bright, and upon bacteriological examination it gave the following results:

| | |
|---|---|
| Bacteria per c.c. capable of growing upon gelatine in three days at 20° C. | 30 |
| The B. coli absent in . . . . . . . . . . . . | 36 c.c. |
| The B. enteritidis sporogenes absent in . . . . . . . | 150 c.c. |

These were excellent results for a shallow well-water and I considered the sample satisfactory. However, learning that the well was near the farmyard I obtained a larger sample and submitted it to a chemical analysis, when the following results were obtained:

| | | |
|---|---|---|
| Chlorine . . . . . . | 21·1 | parts per 100,000 |
| Total hardness . . . . . | 47° | ,, ,, |
| Nitrites . . . . . . | absent | |
| Nitric nitrogen . . . . . | 2·0 | ,, ,, |
| Free ammonia . . . . . | ·035 | ,, ,, |
| Albuminoid ammonia . . . . | ·022 | ,, ,, |
| Oxygen absorbed . . . . . | ·110 | ,, ,, |

The only possible conclusion which could be drawn from this analysis was that the water was seriously polluted by manurial matter. The well was then opened and I found that the brickwork was absolutely concealed by a network of rootlets from trees near, and there was a very polluted horse pond within 80 feet of the well. Whether this feltwork filtered out the bacteria or otherwise destroyed them cannot be said, but it seems probable that the rootlets had something to do with the disappearance of the bacteria. Neither could it be said that the water was the cause of the illness, but it certainly was not a suitable water for drinking and dairy purposes.

The second example is of an exactly opposite character. Some illness of a typhoidal character had occurred at a private house deriving water from a shallow well. The water had always been considered excellent in character. The medical attendant, however, was not satisfied and caused a sample to be sent me for examination. The results obtained upon chemical analysis gave no signs whatever of any pollution, and the water was of excellent appearance. These results were:

| | | |
|---|---|---|
| Chlorine | 5·0 | parts per 100,000 |
| Hardness | 40° | ,, ,, |
| Nitrites | absent | |
| Nitric nitrogen | ·36 | ,, ,, |
| Free ammonia | ·001 | ,, ,, |
| Albuminoid ammonia | ·004 | ,, ,, |
| Oxygen absorbed | ·036 | ,, ,, |

The bacteriological examination gave totally different results:

| | |
|---|---|
| Bacteria per c.c. capable of growing on gelatine in three days at 20° C. | Innumerable |
| Bacteria per c.c. capable of growing on agar in two days at 37° C. | 1100 |
| The B. coli present in | 1 c.c. |
| The B. enteritidis sporogenes present in | 100 c.c. |

There could be no doubt that sewage was trickling into the well, but unfortunately I never heard whether the well was examined. I absolutely condemned the water as unfit for any domestic purposes.

Another interesting experience emphasises the importance of not trusting to a chemical analysis alone, and of not expressing an opinion of a source of supply from a single sample of water taken under favourable circumstances. It is referred to on p. 19. In dry weather this spring yielded a water of great organic purity, but quite possibly a bacteriological examination made at that time would have afforded evidence of pollution, since the water after a heavy rainfall was organically impure and loaded with bacteria derived from sewage.

In the great majority of cases, when a water is submitted for examination it is to determine whether it is suitable for domestic purposes, and a more or less complete analysis has to be made, especial attention being paid to the estimation of the nitrates and ammonias, the hardness and the oxygen absorbed. Occasionally, however, a water is examined to ascertain if it is adapted for a particular manufacturing purpose, when the quantity and character of the saline constituents become of greater importance and ofttimes the ammonia and organic matter can be ignored. Still more rarely a water is known to be unfit for a particular purpose, and the question submitted is whether it can be treated in any way so as to render it suitable. If for drinking and general domestic use, it may be a question whether storage alone, or sand filtration, or passing through a mechanical filter will suffice, or, if not, what combination of processes will render the water safe. The solution of the problem necessitates a study of the source of the water and a series of analyses to ascertain to what extent it is likely to vary in quality, and presents no special difficulty so far as the analyses are concerned. Sometimes it is desirable to soften a hard water of dubious character, and the question arises as to what extent the softening process will remove any objectionable bacteria. Unfortunately experiments conducted on a small scale are useless for this purpose, but experience shows that the softening process, if properly conducted, considerably improves the bacterial character of a water. It is easily possible, however, to disturb the bacteria carried down by the sedimentary matter and to cause the softened water to contain more bacteria than the unsoftened. Some recent results obtained in the systematic examination of a public water supply are recorded in a later section.

The process to be adopted for softening depends upon the character of the hard water. The Permutit system alone is applicable to any kind of water. Clarke's process (use of lime alone) is especially suitable for chalk waters, whilst admixtures of lime and sodium carbonate are necessary for waters with a high permanent hardness. It would appear to be a simple matter to calculate the amount of lime or of lime and sodium carbonate required to soften any water, but such is not the case. A careful determination of all the calcium and magnesium salts enables a calculation to be made, but such a calculation requires to be checked by actual experiments. How this can be done will be described in a later chapter. The carbonates of magnesium and calcium are much more soluble in water than is usually supposed, and if left in solution they are subsequently deposited in the mains. If, on the other hand, an excess of lime is used, this will become carbonated and also cause a deposit. For this reason it is often desirable to select a process which includes re-carbonating the water after softening, as a slight addition of carbonic acid gas prevents any subsequent deposition of carbonates. Chalk water rarely gives any trouble, but waters containing magnesium salts, especially the sulphates and chlorides, are difficult to treat. When a water varies in character from day to day, whatever process is adopted it requires skilled supervision to secure uniformly good results.

This subject is becoming of considerable importance as there is an increasing tendency on the part of consumers to demand a supply of soft water. The saving effected in the humblest household more than compensates for the increased cost of the water. The process to be recommended depends entirely upon the character of the water and of the expenditure which can be afforded. For household supplies and for manufactories requiring an exceedingly soft water, the Permutit system is the best, and on account of the small amount of trouble entailed is probably the cheapest; but for large supplies the expense is considerable, much more than for softening by means of lime and soda.

# CHAPTER IX

## INTERPRETATION OF THE RESULTS OF MICROSCOPICAL AND BIOLOGICAL EXAMINATIONS

A microscopical examination of a potable water should be made whenever the sample shows any signs of turbidity or contains any visible suspended particles, since such an examination will reveal the nature of the suspended or deposited matter, and often assist greatly in the interpretation of the results of a chemical analysis. Where a supply, usually satisfactory, suddenly develops some colour, turbidity, or odour, the microscope almost invariably gives a clue to the cause. Frequently a chemical analysis is useless in such an investigation.

In the examination of streams, lakes, reservoirs, ponds, &c., suspected to be polluted, or known to be polluted, a biological examination may assist in determining the extent to which the water is affected by the filth discharged into it. Low forms of life may be found suspended in the water or growing attached to stones, twigs, water plants, &c., or floating in masses on the surface. These must be examined to ascertain whether they are organisms which only thrive in polluted waters and whose presence therefore proves contamination, or whether they are organisms which later in the season may decay and create a nuisance.

The suspended matter submitted to microscopic examination may be (*a*) of mineral origin, or (*b*) of animal or vegetable origin, and in the latter case may be living or dead. Bacteria requiring great magnifying power to render them visible and special methods for their identification are not included in a microscopical examination, nor in what is spoken of as a biological examination. These special methods are included under the term bacteriological or bacterioscopic examination.

A water sediment is submitted to the scrutiny of the microscope to obtain information for one or more of three purposes: (1) to detect contamination, (2) to elucidate the results of the chemical examination, and (3) to ascertain the cause of any odour, colour, or turbidity.

A public water supply, to be satisfactory, should be entirely free from visible suspended matter, living or dead. Most springs and deep wells yield a water of this character, and if properly stored and distributed, it should reach the consumers in its pristine purity. Storage in open reservoirs, or in reservoirs to which light has access, may result in vegetable or animal growths appearing, and an inadequate system of filtration may contribute both to the fauna and flora of a water. Subsoil waters, river waters, and lake waters usually require filtration; otherwise they will from time to time be delivered in a turbid condition, due to disturbance by heavy rains and floods or to the growth at some particular season of low forms of vegetable or, more rarely, animal life.

The presence of visible particulate matter almost invariably indicates some defect in the water supply, and its character often indicates the nature of the defect and permits of a remedy being suggested.

As chlorophyll is only produced under the influence of light, and diatoms only grow under similar conditions, the presence of diatoms or of green algæ in well-water proves that some water which has been exposed to light has gained direct access to the well, it may be, along the track of the pump pipe or through some aperture near the top. Often the amount so entering is too small to affect the results of a chemical analysis, and without a microscopical examination a danger of this kind may easily be overlooked.

The examination of samples of water taken at regular intervals from large reservoirs will show to what extent such water is affected, at different seasons, by the growth of low forms of vegetable and animal life, and may prove the necessity for the adoption of a system of filtration, or for making improvements in the surroundings of the reservoir for the prevention of water being admitted from objectionable sources. If such waters become discoloured or acquire an odour or taste, a microscopic examination will be far more likely to reveal the cause than a chemical or bacterioscopic analysis.

The examination of water supplied from the mains may show that growths are taking place in the mains, probably at dead ends, and indicate the necessity for more frequent flushing or for some alteration in the connections to allow of more complete circulation. Green growths may indicate defects in the covering of service reservoirs, or of house cisterns. Where vegetable and animal debris is found in water from the house taps, but not from the mains, some defect in the house cistern is almost certain to exist, or there may be a slimy growth in the nozzle of the tap.

The presence of particles of mineral matter alone may indicate surface contamination, or merely the nature of the stratum yielding the water.

The dead organic matter is usually so disintegrated as to be beyond the power of definite identification, and it may be associated with matters of mineral origin, clay, chalk, fine sand, oxide of iron, &c., rendering identification still more difficult.

Search should be made for substances which admit of recognition, such as epithelium, striped muscular fibre, dotted ducts of pine-wood, starch granules, fibres of cotton, hemp, silk, wool and other animal hair, ova, and dead or living vegetable and animal organisms. The presence of granules of wheat, potato, rice, and similar starches, of cotton and other vegetable fibres, of wool, &c., would indicate contamination with sewage or foul surface water. Hairs, scales, parts of insects, &c., may indicate the existence of an uncovered and unprotected house cistern.

In Germany and in the United States of America considerable stress is laid upon the biological examination of waters, by which is meant the identification and approximate enumeration of the various low forms of animal and vegetable life (excluding the bacteria). Even an expert cannot name all the living constituents in a water sediment. Some organisms go through such strange transformations during their life-history that it is requisite to be acquainted not only with the fully developed forms, but also with the various other forms assumed in the cycles of their careers. The Massachusetts State Board of Health have for years past published annually reports on the biological examination of all the public water supplies in the State. The object of these examinations, however, is not so much the detection of pollution as the study of the relation of the odours of a water to the organisms which it contains, the kinds of organisms found in water from different sources, their seasonal distribution, &c. These are all subjects of special interest in that State, where the majority of the water supplies are derived from surface sources, and often give rise to complaint on account either of their turbidity or odour or taste. In this country the conditions are different, and a detailed biological examination would rarely yield results at all commensurate with the labour expended. Even when a chemical and bacteriological examination of a potable water has been made, additional information can often be obtained from a biological examination.

The organisms of importance in the examination of water may be divided into three classes:

(*a*) Those which, either in the living state or in process of decay, impart an odour or taste to the water;

(*b*) Those which by their presence indicate that the water is polluted with sewage or manurial matter, or with organic waste from certain processes of manufacture, since they can only thrive in such polluted waters;

(*c*) Those which can live only in water of considerable purity, and whose presence therefore contraindicates pollution from such sources as the above.

The number of organisms of any real importance is comparatively small, since the majority of those found in water afford no indication as to whether it is pure or impure.

Whipple [1] classifies the various odours which appear in potable waters as 'aromatic,' 'grassy,' and 'fishy,' and for convenience tabulates them and their causes as under :

| Group | Organism | Natural odour |
|---|---|---|
| Aromatic odour . | *Diatomaceæ*— | |
| | Asterionella . | Aromatic, geranium, fishy |
| | Cyclotella . | Faintly aromatic |
| | Diatoma . | Faintly aromatic |
| | Meridion . | Aromatic |
| | Tabellaria . | Aromatic |
| | *Protozoa*— | |
| | Cryptomonas . | Candied violets |
| | Mallomonas . | Aromatic, violets, fishy |
| Grassy odour . | *Cyanophyceæ*— | |
| | Anabæna . | Grassy and mouldy, green corn, nasturtiums, &c. |
| | Rivularia . | Grassy and mouldy |
| | Clathrocystis . | Sweet, grassy |
| | Cælosphærium . | Sweet, grassy |
| | Aphanizomenon . | Grassy |
| Fishy odour . | *Chlorophyceæ*— | |
| | Volvox . | Fishy |
| | Eudorina . | Faintly fishy |
| | Pandorina . | Faintly fishy |
| | Dictyosphærium . | Faintly fishy |
| | *Protozoa*— | |
| | Uroglena . | Fishy and oily |
| | Synura . | Ripe cucumber, bitter and spicy taste |
| | Dinobyron . | Fishy like rockweed |
| | Bursaria . | Irish moss, salt marsh, fishy |
| | Peridinium . | Fishy like clam shells |
| | Glenodinium . | Fishy |

To the above should be added Beggiatoa and certain species of Chara, which give the odour of sulphuretted hydrogen, and Crenothrix.

In an unfiltered water, which has suddenly developed an odour, the offending organism will probably be found in great numbers in the water as supplied to the consumers, whilst in a filtered water the organism will be more likely to be found on the filter beds or in the reservoirs.

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[1] *The Microscopy of Drinking Water*, p. 125.

Whipple does not think that the odour-producing organisms are injurious to persons in good health, but he adds: 'There is some reason to believe that people accustomed to drinking water free from organisms may be subjected to temporary intestinal disorders when they begin to drink water rich in microscopic organisms, just as people are affected by changing from a hard to a soft water and *vice versa.* It is possible that with young children and invalids such disorders may be more common than has been supposed.'

In Massachusetts a large proportion of the surface water supplies have at some time or other given rise to great annoyance by the development of an odour. Apparently, however, few of these waters were subject to filtration, since Whipple thinks one of the most efficient remedies is filtration. As most river and surface waters in this country are filtered before being delivered to the consumers, this may account for the comparatively few recorded instances of public supplies developing any odour.

Unpleasant odours may, however, develop in carefully filtered water. The water supplying Cheltenham is filtered, yet in the spring of 1896 the water became red and turbid, and acquired an offensive smell due to the development of a species of Crenothrix. It was first remarked on March 1 when the large bath at a public school was being filled. The odour was most marked in water which had been heated. When the reservoirs were inspected the whole of the water in one was found to be of a brown-red colour and turbid. The water in the other reservoirs remained quite normal throughout. A reddish deposit was found on the sand filter, and by the end of April this had accumulated to such an extent that the beds became choked. The sand scraped from the surface when exposed in heaps exuded a dark red semi-fluid matter with a 'foul privy' odour. By the middle of May the water in the affected reservoir had acquired an olive purple tint, which gradually changed to green, and by

June 10 the water had acquired its normal colour, though it still remained slightly turbid. The organisms had evidently traversed the filter bed and entered the mains. Dr. Garrett says: 'The ability of the spore cocci to reproduce themselves will account for their swarming in our reservoir, and for their reproduction in, at least, some portion of the pipes—in fact, the study of the visitation constitutes an object-lesson in the ease with which a microbe may develop in the mains of a water service, and pollute a water which has been carefully filtered before being turned into the pipes. There are generally certain portions of the waterpipes where the chance of such a development is greater than elsewhere. I refer particularly to "dead ends" or culs-de-sac, where the water is liable to become stagnant. An intermittence in the supply of any part of the service possesses a similar disadvantage, by leading to the disturbance of any growth or deposit upon the pipes, which will then be washed through the house taps.' This Crenothrix appears capable of developing only in waters containing a trace of iron in solution, and it has given rise to trouble in many towns both in America and on the Continent. The organism found in the Cheltenham water corresponded in the main with the description given by Kuhn of the Crenothrix polyspora, but certain differences caused it to be regarded as a variety, and Dr. Garrett called it Crenothrix polyspora var. Cheltoniensis. There are, doubtless, several species of Crenothrix. I have recently had to investigate complaints made with reference to the water supply to a town in East Anglia. The water is unfiltered and derived from subsoil springs. The supply has for some time been intermittent, and recently complaints have been received of bits of substance resembling raw potato coming through the house pipes, together with oxide of iron. When the street hydrants are open, quantities of this gelatinous material, in thin sheets, are washed through. When kept it acquires an offensive fishy odour. The growth appears to be a kind of Crenothrix. The typical Crenothrix I have previously found in several subsoil waters submitted to me on account of their having acquired an unpleasant odour and appearance. In connection with Crenothrix infection it is interesting to note that Dr. Garrett found the organism had no effect upon health. He says: 'Although, for many weeks during which it was affected, the water from the Dowdeswell Reservoir continued to constitute the main supply to the town, and although there were many complaints of the odour, appearance, and unpalatability of the water, there was no evidence to prove that the organism, which was being consumed in great numbers, had any pathogenic influence.'

In 1891 the water supplying Bolton (Lancs.) acquired a 'fishy' odour and taste. The reservoirs were found to be swarming with a confervoid growth, to which Dr. Adams attributed the odour and taste. It proved to be the Conferva bombycina of Kutzig, an organism often found in ponds and ditches; but why this sudden infection of an immense volume of water should have occurred is difficult to explain. Dr. Adams regarded its growth as being fostered by the presence in the water of phosphates, derived from manure and sewage on the watershed area.

In 1898 the water in a large reservoir supplying another important Lancashire town became infected with the same organism. A sample of the water was submitted to me. There was little difficulty in identifying the nature of the growth. Upon visiting the reservoir I found the water was rather low, and that the growth was taking place in the shallows, and was being gradually diffused through the water in the reservoir towards the outlet. The supply was not filtered, and when fine muslin was tied over any of the house taps in the town it was easy to collect a considerable quantity of the confervoid growth. In passing through the mains the cells disintegrated and imparted a faint odour and taste to the water. The reservoir water containing the living plant was devoid of odour.

Of the organisms, other than bacteria, whose mere presence in a water indicates pollution of any definite character, there are few which occur with sufficient constancy, and in sufficient number, to render desirable a special search being made for their detection and identification. In deep and shallow well-waters, and in spring-waters, the occurrence of any of the low forms of animal and vegetable life such as we are considering indicates inadequate protection, or unnecessary exposure to light. Uncovered service reservoirs are very subject to algoid growths, and all kinds of minute animals may gain access. Covered tanks, if lighted, are also likely to become infected with green algæ. Uncovered house cisterns may become the repository of all kinds of filth. Some years ago I was asked to investigate the water supply to a private house, which had in a few days acquired an opalescent appearance, and a disagreeable odour and taste. As the supply came from the public mains, and was known to be satisfactory, I at once suggested an examination of the cistern, which was placed near the ceiling in the scullery. This was found to contain a piece of pork (about 1 lb.), a quantity of bread, remains of a packet of dry soap, and pieces of wall paper. These must have been wilfully placed in the cistern by one of the servants. A biological examination of the water was unnecessary.

In another instance, where the public water supply was above suspicion, the water from the house tap contained particulate matter and a large number of bacteria, including the Bacillus coli. When I examined the large tap from which the water was obtained, I found it contained a quantity of shiny matter, looking like boiled sago. It was a mass of zooglœa, and to this I attributed the contamination of the water, as after 'flaming' the tap the water no longer contained an excessive number of bacteria nor the Bacillus coli, and was free from particulate matter.

The following organisms should be sought for in streams into which sewage or trade effluents discharge. The four in the first column are all forms of what is popularly called the sewage fungus, because they are confounded with each other very frequently, and all are liable to occur in sewage farm and bacteria bed effluents, and in streams receiving sewage or organic trade refuse:

Sphærotilus natans
Leptomitus lacteus
Beggiatoa alba
Carchesium Lachmanni

Oscillatoria tenerrima
Oscillatoria brevis
Oscillatoria tenuis
Oscillatoria antliaria
Oscillatoria Frœlichii

Mez, who has made a special study of the organisms found in different kinds of water, states that the following are frequently found, and that if they occur in abundance, their presence indicates some measure of pollution :

Amphimonas fusiformis
Amphimonas globosa
Anthophysa vegetans
Aspidisca costata
Aspidisca Lynceus
Chilodon Cucullus
Chilodon uncinatus
Colpidium Colpoda
Colpoda Cucullus
Dimorpha longicauda
Enchelys silesiaca
Euglena olivacea
Euglena velata
Euglena viridis
Euplotes Charon
Euplotes patella
Glaucoma scintillans
Hexamitus inflatus
Hexamitus rostratus
Lionotus fasciola
Loxophyllum Meleagris
Monas guttula
Monas vivipara
Monas vulgaris
Bodo caudatus
Bodo minimus
Bodo mutabilis
Cercomonas crassicauda
Cercomonas lacryma
Oikomonas mutuabilis
Oikomonas Termo
Oxytricha fallax
Oxytricha pellionella
Paramaecium Aurelia
Paramaecium caudatum
Peranema trichophorum
Phyllomitus amylophagus
Pleuromonas jaculans
Polytoma uvella
Stylonychia Mytilus
Tetramitus rostratus
Trepomonas rotans
Trepomonas Steinii
Urocentrum turbo
Urostyla multipes
Urotricha farcta
Urotricha lagenula

The Sphærotilus natans, Leptomitus lacteus, Carchesium Lachmanni and Beggiatoa alba form tufts of filaments, like bits of cotton wool, though often coloured, adhering to stones, twigs, waterplants, debris, &c., in running water. They are not found in crude sewage, as their growth requires that the water should be aërated. To the naked eye the resemblance is too close for any but a trained observer to distinguish between them.

The Sphærotilus natans flourishes best in waters polluted with the discharges from breweries, sugar refineries, starch works, tanneries, and sewage works. It is most abundant during the winter months, and its presence indicates excessive pollution.

The Leptomitus lacteus will not flourish in very impure water, but may grow luxuriantly in good sewage effluents. The Carchesium Lachmanni is a member of the animal kingdom, and has been little studied in this country. Dr. Mez refers to it in some detail as being especially characteristic of sewage pollution. It is closely allied to the Vorticellæ, and has, apparently, hitherto been generally confounded therewith. Although chiefly prevalent during the colder months, it is also found in the summer months. Its presence does not necessarily imply a high degree of pollution, but the probability of serious contamination is accentuated if it is found associated with Leptomitus or Sphærotilus in the colder months, or with Beggiatoa or Oscillatoria in the warmer season. It rapidly dies when removed from its natural habitat, and, as it is much more difficult to recognise when all its movements have ceased than when living, it should be searched for within a few hours of collection.

**Beggiatoa alba.**—This fungus, which coats the bottoms of streams, &c., with a white or greyish velvety covering, is usually found in stagnant or slowly moving water containing sulphuretted hydrogen, but it is frequently found in other polluted waters, even in well-waters.

The Beggiatoa have been especially studied by Winogradsky and Cohn. Many different species have been described, all capable of secreting sulphur. In some instances this element may form 90 per cent. of the total weight of the dried organism. Winogradsky is of opinion that the sulphur is derived from the sulphuretted hydrogen found in the water, and that the Beggiatoa do not produce this compound. Cohn, on the other hand, thinks these organisms are capable of decomposing albuminous matter, and even sulphates, with the production of sulphuretted hydrogen. Certain it is that the Beggiatoa are usually found in water containing this gas, and if this gas is present it appears to be immaterial whether the water contains organic impurities or not. Thus the growth is found in the water from natural sulphur springs, as well as from sewage-polluted streams. Save in the natural sulphur springs, sulphuretted hydrogen is chiefly found in the waters of marshes, polluted streams, and in stagnant shallow bogs, such as are found on the Danish Zeeland coast and the Limanes, along the coast of the Black Sea. In all the latter cases it seems probable that the sulphuretted hydrogen results from the decomposition of organic matter, and possibly, under certain circumstances of sulphates, by bacteria. Hoppe-Seyler believed that bacteria decompose cellulose with the formation of marsh gas, and that the nascent gas, acting upon calcium sulphate, gives rise to calcium carbonate, sulphuretted hydrogen, and water.

The Beggiatoa then decompose the sulphuretted hydrogen, storing up the sulphur in the free state, and afterwards oxidising it as required into sulphates. In this way the sulphur cycle is completed, as the sulphates taken up by, or found in the plants, are deposited in the cells in the form of complex organic compounds. Wherever the Beggiatoa are found, pollution of the water by organic matter undergoing putrid decomposition is to be suspected, but inasmuch as sulphuretted hydrogen may, as we have seen, be derived from other sources, the presence of this organism is not absolute proof of pollution.

The second report of the Royal Commission on Sewage Disposal, published in 1902, contains a very interesting report on 'The pollution of the river Severn,' by Messrs. Boyce, MacConkey, Grünbaum, and Hill, which includes a section on the 'Sewage Fungus.' They have had opportunities of studying the various organisms included under the general name of 'sewage fungus,' found in various polluted streams.

At Dewsbury, where they first met with the fungus, it occurred at the mouth of the main effluent from the sewage farm. The effluent was clear; the tufts of fungus very long and of a rusty colour, from a deposit of oxide of iron. The form was subsequently identified as Leptomitus lacteus. At Birmingham, in the stream receiving the various effluents from the sewage works, it occurred in enormous quantities, and had to be removed by screens to prevent secondary decomposition. The discovery of the fungus in a stream near Shrewsbury led to the detection of a previously unsuspected source of pollution from a workhouse. This form proved to be Sphærotilus natans, which was afterwards found in the river Alt, producing characteristic tufts attached to the stones at the bottom of the river. In text-books the sewage fungus is almost invariably described as being the Beggiatoa alba, an organism which is only occasionally found in sewage effluents. Apparently this is also the experience of Professor Boyce and his colleagues, since they do not refer to it in the following paragraph, which gives the result of their observations. 'Classed under the heading of "sewage fungus" are certain distinct growths, the most highly organised of which is the Leptomitus, one of the Saprolegniaceæ, and therefore comparatively high in the scale of fungi. Next to it comes the Sphærotilus, which may be placed among the more highly developed forms of bacteria. There are also several bacterial zooglœa masses, which may assume a branching appearance and simulate a sewage fungus. . . . In polluted brooks all the appearance of the typical fungus was sometimes caused by extensive growths of a protozoon, the Carchesium Lachmanni.'

The presence of Sphærotilus, they found, indicated much greater pollution than the presence of Leptomitus, the latter only occurring in well-oxygenated and comparatively slightly polluted waters, whilst the former grows well in any oxygenated sewage effluent. The zooglœa masses above referred to are regarded as being closely allied to the Sphærotilus, if not identical therewith, and 'flourish best where the stream of sewage is most active and thinnest.' They found the Carchesium Lachmanni in great masses under similar conditions to those of the Sphærotilus, and they regard all the above low forms of life as playing no unimportant part in the process of sewage purification. They also found the Euglena viridis in certain field drains, and in an effluent from a coke bed upon which sewage was being treated. The Sphærotilus is probably most frequently confounded with Beggiatoa by inexperienced observers. According to my experience, the latter is chiefly found living in waters containing sulphuretted hydrogen, whilst the former rarely, if ever, occurs in such a water. Recently, however, I found an organism closely resembling, if not identical with, the Sphærotilus, in water polluted by the waste liquor from a paper works. This polluted water had a decided odour of sulphuretted hydrogen, and contained a considerable amount of sulphates. Masses of these organisms from time to time become detached from the stones, &c., upon which they have been growing, and, floating on the surface of a stream, enter into decomposition and give off most offensive odours, that of sulphuretted hydrogen generally predominating.

**Oscillatoria.**—These filamentous algæ are almost ubiquitous. They are found in all streams, whether the water be pure or impure. The non-motile forms, however, are rarely found in unclean waters, whilst a few of the motile forms are, according to Mez, very characteristic of polluted waters. The latter are nearly always black, and cover the beds of streams or the damp sloping banks. Floating organic debris covered with these organisms often occurs in masses on the surface of polluted streams. At certain periods these smell most offensively, and are popularly looked upon as being composed of fæcal matter which has escaped from drains, sewers, or sewage works. They abound in the summer or autumn, differing therefore in seasonal distribution from the other organisms most frequently associated with polluted streams. They are undoubtedly nature's scavengers preparing the way for the appearance of higher forms of vegetable and animal life.

In examining streams other definite organisms, characteristic of particular kinds of pollution, have occasionally to be sought for, as, for example, yeast, when contamination by brewery refuse is suspected.

**Examination of Sand Filters.**—The examination of filter beds may be conveniently considered in this place, since a knowledge of the biology of sand filtration is essential, in order that such an examination may be intelligently conducted.

Assuming that the filter beds are properly constructed, sufficient in number, and carefully supervised, it is not unusual for a bed which may have been acting properly for days to suddenly pass water containing an excessive number of bacteria. It is for this reason that daily observation of the water from each bed is so requisite, for which purpose some arrangement is necessary to enable samples to be taken of the filtered water, and to 'cut out' of the system any bed not working properly. Unless this is done, one filter may be passing an impure water for some time before it attracts attention, and when such a defect is discovered, without the arrangement for obtaining samples from each bed, it would be often difficult to localise it. The discovery of the cause, in consequence of which a bed suddenly loses its efficiency, often taxes to the utmost the skill and experience of the engineer and biologist; but a knowledge of the causes discovered and recorded in previous cases, and of the principles underlying the process of sand filtration, will generally enable the investigator to arrive at a satisfactory conclusion. Notwithstanding the importance of this subject, it receives little attention in this country; but in Germany, Holland, and America a large amount of systematic work has been done. In many large works in these countries biologists are constantly employed making observations at properly equipped stations. Dr. Kemna, who has charge of the station at the Antwerp Waterworks, recently contributed an interesting and valuable paper on the 'Biology of Sand Filtration' to a meeting of the Institute of Water Engineers, and I am indebted to his paper for much of the following information.

When a filter is started, it at first acts only as a coarse strainer, but in two or three days a slimy layer forms upon the surface of the sand, and true filtration commences. Green and blue algæ have interwoven their filaments into one felted sheet; diatoms, with their siliceous frustules and gelatinous envelopes, fill up the meshes, zooglœa adhere to every particle, and innumerable bacteria dot the whole mass. Besides the plants generally resting on the top of the sand, there are others which float on account of their protoplasm containing oil globules or bubbles of gas. The bottom dwellers occasionally rise to the surface when the oxygen, evolved during their rapid growth, accumulates in their entangled masses. When such masses are seen rising to the surface the yield of the filter should be at once diminished, or the filter be thrown out of work, as the bacteria in the filtered water markedly increase in number under those conditions. The floating species fall to the bottom when they die. They sometimes occur in enormous numbers, imparting a distinct colour to the water, in which case the filters speedily become choked, the quality of the water is impaired, and it may acquire an offensive odour. Practically all the odour-producing organisms are floating forms. The colouring matter of the green algæ gets liberated, and may form a scum on the surface of the water, sticking to everything like oil paint. There is apparently a certain regularity in the seasonal appearance of the plants constituting the filtering film. Diatoms abound all the year round, but are specially abundant in winter. Green algæ appear in spring, and develop to a large extent in summer. The blue algæ are numerous in the hottest months, but disappear in winter. Dr. Kemna finds at Antwerp that the dominant forms are Melosira varians, Fragilaria capucina, and Spirogyra tenuissima, the proportions being about five, four, and one respectively. A growth of Hydrodictyon, a green alga, with the cells in pentagonal meshes, may cover the whole, and when the filters are cleansed this growth may be rolled up like a carpet.

Dr. Kemna refers to the following organisms as giving trouble to the water engineer: the fresh-water sponge, Spongillia, is of frequent occurrence in ponds and reservoirs and, while living, tends to purify the water, but when dead it decays and gives off a most offensive odour. A fresh-water polyp, the Bryozoa, has a tendency to fix itself to iron, something like a growth of moss, and as it grows within a water main may considerably reduce its calibre, and impart 'a most awful taste to the water.' The Crenothrix may gain access to the filtered water, the growth appearing in tufts of yellowish or brownish colour, and may be so abundant as to block up lengths of mains. This has occurred at Rotterdam, Berlin, and elsewhere. The Cladocera, the most common form of which is the water-flea, Daphnia, may breed in spring in such numbers as to render the reservoir water turbid, and their dead bodies may form a thick layer on the filter bed. Dr. Kemna tells of ten tons being screened from one reservoir in a single season. Two insects are mentioned as sometimes affecting sand filters. One is a kind of gnat, named Chironomus, having an aquatic larva of red colour, usually called the blood-worm. These burrow in the sand, but when they are transformed into winged insects they come to the surface, and, the tubes remaining empty and open, the filtering surface is riddled with innumerable holes, and the number of microbes in the effluent suddenly increases. The eggs of the Chironomus are embedded in a gelatinous cord, and sometimes the sides of a filter at water-level are covered all round with these streamers.

The second form is the hemipterous Corixa, resembling somewhat the water-boatman, Notonecta. These may be so abundant as to render the water on the surface of the filter turbid by their activity in tearing up the sediment. They do not, however, appear to disturb the filtering surface to such an extent as to impair the quality of the effluent. Dr. Kemna mentions two vertebrates which have given trouble. One is the eel, which, when young, may get into the air channels provided to allow air to escape when a dry bed is refilled, and then into the water beneath. These air pipes, he suggests, should be covered with fine wire gauze. The other is the stickle-back, which spawns about the beginning of May. He mentions that on one occasion, towards the end of the month, the microbes in the filtered water at the Wælhem Works suddenly increased from an average of about 20 to over 200 per cubic centimetre. The filter was examined, and it was found that there were patches of sand with the surface perforated, each group of perforations being regularly distributed round a central larger hole. This central hole was covered up by threads of algæ, weighted with small pebbles, and under this covering there was a mass of eggs of the ordinary stickle-back (*Gasterosteus aculeatus*). Probably the male, in searching for building materials, made the numerous small holes surrounding the nest.

The organisms forming the '*schlammdecke*' of a 'ripe' filter vary with the source of the water being filtered. Waters from uplands and uncultivated moorlands form a deposit of slime of a different character from that of waters from cultivated ground or from rivers flowing through fertile valleys. The latter often form a *schlammdecke* rich in filaments of fungoid origin. The same filter bed often yields from different portions of its surface organisms of different type. On such occasions an examination of the dry surface of the filter will show marked variations in colour; sometimes the whole surface is dotted over with more or less circular patches of a reddish or yellowish green, the remainder of the surface being of a uniform green. These patches obviously result from the growth of certain algæ from and around a spore or filament which has been arrested by the filter. The dead and living forms of algæ and of fungi, &c., found in the *schlammdecke*, are wellnigh innumerable, and they are agglutinated together by bacterial zooglœa.

Recent investigations are said to indicate that this *schlammdecke* is not essential to efficient filtration. At Bedford I recently saw a sand filter fed with water by means of a Candy's sprinkler, which was giving excellent results. There was no slimy growth covering the surface, but the upper two inches or so of the sand was slimy and discoloured.

If a sand filter is used intermittently, unicellular algæ may permeate the whole of the sand and appear in the filtered water. I had a sample of water from a town's supply submitted to me, which was said to be filtered and which swarmed with protococci. I examined the sand filters and found that one had recently been brought into use after standing idle for some months. The sand was wholly impregnated with this growth, and when the filter was cut out the cause of the trouble was removed.

Mechanical filters are alleged to permit of low forms of animal and vegetable life developing in the interior, and I have had many samples of water containing such organisms from filters of this character. Here, again, I suspect that growth can only occur when the filters are used intermittently, and in one case I attributed the growths found in the water from the mains to imperfect protection of the reservoirs collecting the filtered water.

The plates at the end of the section on the Microscopical and

Biological Examination of Water illustrate all the more important animal and vegetable organisms, &c., referred to in this section. With one or two exceptions they are drawn from actual specimens which I have found in examining waters from various sources, and in examining the surface of sand filters. A study of them will show how difficult it is to determine the true nature of many of the objects revealed by the microscope. Fortunately it is not always necessary to specifically identify every organism discovered in order to correctly interpret the results of the examination.

# CHAPTER X

## THE INTERPRETATION OF THE RESULTS OF THE BACTERIOSCOPIC EXAMINATIONS OF WATERS

The danger arising from the use of a polluted water is probably never due to the organic matter in solution, or to the dead organic matter in suspension, but to living organisms—bacteria. A chemical analysis can tell us nothing about the presence or absence of these, and, as we have seen, a water may contain very large numbers of such organisms, and yet be chemically of a very high degree of purity. It would appear, therefore, that, for the detection of dangerous pollution, a bacterioscopic examination is of greater importance than a chemical analysis, and that in some cases a chemical examination may be superfluous. Too great an importance must not, however, be attached to bacterioscopic results, since great care is required in their interpretation. Want of experience, or a too rigid adherence to empirical standards, may easily lead to erroneous conclusions. Some knowledge of the history of a water is in most cases absolutely necessary in order to enable correct inferences to be drawn. We must know not only the source of the water, but the mode of its collection, the period which has elapsed since the sample was taken, the conditions under which it has been kept, &c. Even when the number of bacteria present in the sample is ascertained, it must not be forgotten that it is the nature rather than the number which it is of importance to determine. An immense number of different species of bacteria are found in water, and the majority are apparently quite harmless, their presence having no known significance. Many of them are exceedingly difficult to recognise. Some, which, if present, it is of great importance to detect, so closely resemble others of no importance that very considerable skill is required to effect the differentiation. Even those which are of importance, because their presence usually indicates pollution, may have been derived from harmless sources and their presence may have little real significance. Moreover, waters actually known to have caused, or to be causing, diseases such as enteric fever and cholera may be examined by the most expert bacteriologist without the specific organisms being detected, and a water liable to specific pollution may, even on repeated examination, be found free from the organisms indicating such pollution. Volumes have been written on the bacteriological examination of water, yet the sum total of the information available, bearing upon the interpretation of the results, is comparatively small. For a time views were undergoing constant change, new methods were being constantly devised, and old ones discarded, but during the last few years certain methods of examination have obtained general acceptance, and now discussions chiefly arise upon the interpretation of the results. It is not, therefore, my intention to cover the whole ground included in the study of bacteria found in water, but to limit my attention almost exclusively to the bacteria which are of importance in the examination of waters for the detection of pollution derived from sewage or of manurial origin. Such pollution may be very recent or may have occurred at some distant period in the history of the water. With the exception of rain-water collected from clean rocky or moorland surfaces, probably all waters at some period in their history come in contact with, and take up, sewage or manurial matters. The extent of this pollution is chiefly indicated by the amount of nitrates present in the waters, and can only be ascertained by a chemical analysis. Bacteriology can tell us but little, if anything, of such past pollution. At the present time the utmost that can be expected of the bacteriologist is that he shall say whether a water does or does not contain certain organisms which are usually associated with sewage and manure, and which, either by themselves or by their association together, indicate pollution.

The character and scope of a bacteriological examination will, naturally, vary with the object for which it is performed. Such examinations may be made for any of the following purposes :

1. To detect pollution with sewage or manurial matter.
2. To ascertain the efficiency of a system of filtration or other method of water purification.
3. To ascertain the effect of flow upon rivers and streams, or of rainfall upon streams, springs, and wells.
4. To ascertain the cause of some change observed in a water.
5. To detect, if possible, specific organisms during the epidemic prevalence of some water-borne disease.

The bacteriological examinations made for the above-mentioned objects can be divided into two classes : (1) the determination of the number of bacteria present in a given quantity of the water ; (2) the identification of particular organisms or groups of organisms and an approximate estimation of their number.

When bacteriology was first applied to the examination of water, the estimation of the number of organisms present was held to be of the highest importance. When this idea had been exploded, the number of different kinds of organisms rather than the total number was regarded as being the more important, but latterly this view has received less support, and now it is deemed absolutely necessary to examine a water for certain definite microbes, the number of other organisms present being considered of comparatively trifling importance.

**1. The Number of Bacteria present in Water.**—The enumeration of the bacteria present in a water is of the greatest importance when the object is to ascertain the effect of filtration, but to determine the efficiency of a system something more than an occasional bacteriological examination is required. The arrangements for filtering should be inspected. Almost any kind of filter may on occasions yield a satisfactorily filtered water, but what is or should be required to be known is whether the apparatus or arrangement can be trusted to give a uniformly good water under all ordinary circumstances. I have examined installations which at first gave practically sterile water, but which after a time yielded a filtrate containing more organisms than the unfiltered water. As previously stated, no system can be considered satisfactory unless it is sufficiently large to filter considerably more than the amount daily required, thus admitting of one or more filters being thrown out of use for recharging, cleansing, and repairing. Each filter, or filter bed, should be complete in itself and be separately connected with the filtered water reservoir, so that samples of water can be obtained from each filter, and at any time a filter can be cut out of the system and the water directed into another channel. There should also be an arrangement for regulating the rate of filtration.

When properly constructed and worked there is no difficulty in producing with sand filters a water which will uniformly contain less than 100 micro-organisms per c.c. capable of growing upon nutrient jelly at 20° C. in three days. The standard originally suggested by Koch was 100 bacteria per c.c. growing in two days, but the above is the standard now generally adopted. Of course, it is understood that the sample examined is taken direct from the filter and plated almost immediately, or has been kept in an artificially cooled receptacle whilst in transit from the works to the laboratory.

Filtration works which produce uniformly a water containing less than 100 bacteria per c.c., capable of growing upon gelatine in three days, may, if otherwise satisfactory, be considered efficient.

This statement refers to samples of water collected at the filter beds ; if taken after the water has traversed a long length of main, or after it has passed through a service reservoir, even the most efficiently filtered water may give much higher results, especially in summer and autumn. This important point is often overlooked. A larger number of bacteria found in a tap water does not necessarily indicate that an imperfectly filtered water is being supplied from the works.

Occasionally the best managed works may send out a water containing a large number of microbes, but as soon as this is detected the individual filter beds should be examined to discover which are at fault. The average standard obtainable at the best managed works may be gathered from a study of the annual and monthly reports of Dr. Houston, the Director of Water Examination, Metropolitan Water Board. The following figures are taken from various Tables in the Report for the year ending March 31, 1911.

Average Number of Microbes per c.c. growing on Gelatine at 20–22° C. counted on the Third Day

| Date | Rainfall | | Raw Waters | | | Filtered Waters[1] | | |
|---|---|---|---|---|---|---|---|---|
| | Thames Valley | Lea Valley | Thames Water | Lea Water | New River Water | Thames Water | Lea Water | New River Water |
| 1909–10 | 32·33 | 28·85 | 5,310 | 35,217 | 2,786 | 14·3 | 21·9 | 10·0 |
| April 1910 | 2·13 | 1·95 | 2,350 | 15,800 | 2,700 | 17·1 | 18·3 | 11·1 |
| May | 1·96 | 2·56 | 2,272 | 3,800 | 1,098 | 19·5 | 28·7 | 8·1 |
| June | 3·64 | 2·60 | 1,320 | 1,950 | 555 | 16·7 | 26·0 | 6·8 |
| July | 2·25 | 1·83 | 1,625 | 3,675 | 1,060 | 15·3 | 14·7 | 8·1 |
| August | 2·88 | 2·35 | 2,100 | 1,340 | 462 | 19·0 | 23·8 | 8·6 |
| September | 0·46 | 0·90 | 6,740 | 4,750 | 1,090 | 13·8 | 36·2 | 5·8 |
| October | 3·48 | 2·32 | 1,990 | 2,800 | 1,180 | 14·9 | 9·9 | 4·4 |
| November | 3·61 | 3·60 | 14,325 | 74,300 | 6,675 | 13·8 | 27·6 | 15·7 |
| December | 5·21 | 4·13 | 20,225 | 36,950 | 5,400 | 18·5 | 31·1 | 26·1 |
| January 1911 | 1·21 | 1·31 | 9,360 | 11,000 | 1,900 | 17·2 | 20·9 | 15·3 |
| February | 1·67 | 1·35 | 7,325 | 8,375 | 2,800 | 14·7 | 33·9 | 9·4 |
| March | 1·99 | 2·14 | 6,825 | 21,750 | 3,475 | 13·0 | 27·2 | 9·9 |
| Totals 1910–11 | 30·49 | 27·04 | | | | | | |
| Averages 1910–11 | | | 6,184 | 14,709 | 2,273 | 15·9 | 24·4 | 10·5 |

This Table shows:

1. The difference in character of the three rivers from which the raw water is derived.
2. The effect of season and rainfall upon each stream.

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[1] The samples are all collected as the water leaves the filter beds, and not taken from the water mains in the districts supplied.

3. The character of the water from each after storage and filtration.

4. That, generally speaking, the best raw water yields the best filtered water, and the worst raw water the worst filtered water.

5. The high standard of excellence maintained notwithstanding the extreme variation in the number of bacteria in the raw waters.

All the results in Dr. Houston's laboratories are taken on the third day, the counts are therefore presumably taken sixty to seventy-two hours after plating. These figures consequently cannot be compared with counts made on the fourth day or later. It is important to remember this, as many waters contain slowly growing microbes, the colonies of which are not visible on the third day. Certain mechanical filters often yield water of this character. I have found such a water show only twenty to thirty colonies on the third day, and on the fourth day give evidence of a far larger number, but on the sixth day the colonies have been practically innumerable. The bacteria capable of growing on agar at 37° C. within twenty to twenty-four hours vary to a much less extent than the bacteria growing on gelatine at 20–22° C. in three days. Here, again, the growth at the end of two days may far exceed the growth at the end of one day, hence when comparing results it is absolutely necessary that the period of growth should be approximately the same. *Neither the gelatine nor agar count pretend to represent the total number of bacteria present capable of growing on those media, but merely the number capable of producing visible colonies within the given time.*

The following Table (p. 191) is also taken from the same Report by Dr. Houston.

A study of this Table shows :

1. That the variations in the number of microbes growing at 37° C. is not nearly so great in the raw waters as is the variation in the number of those growing at 22° C.

2. That in the raw waters the proportion of agar colonies to gelatine colonies is highest when the raw water is at its best,

judged from the gelatine count; and lowest when the raw water is worst, judged by the same standard.

3. That in the filtered waters the ratio is variable and affords no index whatever to the quality of the water.

Number of Microbes per c.c. capable of growing on Agar at 37° C. in Twenty to Twenty-four Hours

| Date | Raw Waters | | | Filtered Waters | | |
|---|---|---|---|---|---|---|
| | Thames Water | Lea Water | New River Water | Thames Water | Lea Water | New River Water |
| 1909–10 . . . | 495 | 837 | 129 | — | — | — |
| April . . . . | 139 | 389 | 57 | 1·8 | 2·0 | 3·0 |
| May . . . . | 94 | 139 | 47 | 2·9 | 2·0 | 2·0 |
| June . . . . | 400 | 345 | 61 | 5·5 | 10·0 | 1·8 |
| July . . . . | 208 | 752 | 89 | 3·2 | 7·8 | 2·2 |
| August . . . | 600 | 275 | 91 | 3·4 | 6·6 | 1·5 |
| September . . . | 111 | 310 | 61 | 2·6 | 16·6 | 0·9 |
| October . . . | 165 | 255 | 65 | 1·4 | 2·5 | 0·6 |
| November . . . | 522 | 1,228 | 287 | 1·2 | 1·6 | 4·6 |
| December . . . | 760 | 942 | 159 | 3·0 | 1·3 | 8·9 |
| January . . . | 340 | 360 | 70 | 4·0 | 1·1 | 5·1 |
| February . . . | 350 | 152 | 142 | 2·1 | 1·3 | 2·0 |
| March . . . | 415 | 670 | 185 | 1·7 | 1·6 | 2·6 |
| 1910–11 . . . | 339 | 467 | 106 | 2·7 | 3·5 | 2·9 |

The Lea water, when filtered, is the worst of the waters supplied, and the New River water the best, and the Thames water intermediate. In the three cases the ratio of the agar to the gelatine counts are as under:

| | | | |
|---|---|---|---|
| New River . . . . | 2·9 : 10·5 | approximately | 1 : 3 |
| Thames . . . . | 2·7 : 15·9 | „ | 1 : 6 |
| Lea . . . . . | 3·5 : 24·4 | „ | 1 : 7 |

Certain bacteriologists assert that in pure waters the ratio should never be less than 1 : 10, and I recently saw certain waters condemned because the proportion was more than 1 : 10. As a matter of fact, the ratio is of no value save for comparing the same water at different times and under different circumstances. The following are a few determinations made in my laboratories and taken at random from waters examined during the present year.

The variations in the ratios are so excessive, considered either in relation to waters from different sources or to waters from the same source at different times, that it is difficult to draw any conclusions from them. Waters from some sources appear to

| Source of Water | Colonies per c.c. | | Ratio Gelatine to Agar |
|---|---|---|---|
| | Gelatine | Agar | |
| Unpolluted deep well in chalk | 56 | 11 | 5 : 1 |
| ,, ,, | 18 | 10 | 2 : 1 |
| ,, ,, | 32 | 18 | 2 : 1 |
| ,, ,, | 104 | 18 | 6 : 1 |
| ,, ,, | 480 | 48 | 10 : 1 |
| ,, ,, | 820 | 68 | 12 : 1 |
| Unpolluted spring-water | 84 | 24 | 3½ : 1 |
| ,, ,, | 24 | 2 | 12 : 1 |
| ,, ,, | 32 | 6 | 5 : 1 |
| ,, ,, | 18 | 2 | 9 : 1 |
| ,, ,, | 42 | 4 | 10 : 1 |
| ,, ,, | 20 | 2 | 10 : 1 |
| Mountain stream | 10 | 10 | 1 : 1 |
| ,, | 37 | 9 | 4 : 1 |
| ,, | 88 | 18 | 5 : 1 |
| ,, | 350 | 50 | 7 : 1 |
| Polluted river-water | 2,250 | 200 | 11 : 1 |
| ,, ,, | 117 | 33 | 4 : 1 |
| ,, ,, | 2,200 | 90 | 2½ : 1 |
| ,, ,, | 90 | 6 | 15 : 1 |
| ,, ,, | 76 | 38 | 2 : 1 |
| ,, ,, | 146 | 4 | 36 : 1 |
| ,, ,, | 170 | 14 | 12 : 1 |
| ,, ,, | 54 | 10 | 5 : 1 |
| ,, ,, | 155 | 55 | 3 : 1 |
| Spring-water collected in five different reservoirs | 1,100 | 2 | 550 : 1 |
| ,, | 184 | 1 | 184 : 1 |
| ,, | 172 | 2 | 86 : 1 |
| ,, | 342 | 1 | 342 : 1 |
| ,, | 242 | 4 | 60 : 1 |
| ,, | 1,620 | 3 | 540 : 1 |
| Above water filtered | 150 | 1 | 150 : 1 |
| Deep well-water unpolluted | 74 | 2 | 37 : 1 |
| ,, ,, | 16 | 4 | 4 : 1 |
| ,, ,, | 46 | 10 | 5 : 1 |
| ,, ,, | 34 | 6 | 6 : 1 |
| ,, ,, | 158 | 14 | 11 : 1 |
| ,, ,, | 94 | 2 | 47 : 1 |
| ,, ,, | 24 | 8 | 3 : 1 |
| ,, ,, | 36 | 2 | 18 : 1 |

contain very few agar-growing bacteria, compared with those growing on gelatine; in others the agar count is relatively high. Knowing the general ratio for any given water, any marked deviation may suggest inquiry as to the cause, but unless there is some other change the variation may be of no significance. My experience is that, as a rule, variations in the ratio are purely accidental and have no significance whatever.

A study of the Table on the opposite page shows that the ratio is valueless as an index of the quality of any water, and that no reliance whatever can be placed upon it. In fact, neither the gelatine count nor the agar count, nor the ratio between the two, are of any great value, and frequently they are very misleading.

Filtered waters should always be examined for objectionable microbes. If the standard, 100 colonies per c.c. on gelatine, is slightly exceeded, the fact is of little consequence if objectionable bacteria are absent or relatively very few in number, and the water may be passed as satisfactory; whereas if the 100 is not exceeded and the objectionable bacteria are relatively abundant, the water cannot be considered to be satisfactory. In my laboratories filtered waters are always examined for the B. coli and the B. enteritidis sporogenes and occasionally for streptococci, and the quality of the water is judged from the results of the whole examination.

In unfiltered water the number of bacteria varies enormously; but there is no doubt that in really good waters from springs, shallow wells, and deep wells there are rarely 1000 per c.c. capable of growing upon gelatine in three days, but on occasions this number may be exceeded. The character of the source has always to be taken into consideration in such an investigation, as upland and moorland surfaces yield waters which normally contain more bacteria than waters from springs and deep wells. River-waters vary from day to day, and a very slight rainfall often suffices to send up the number of bacteria present considerably. How little reliance may be placed upon the mere enumeration of the number of bacteria is shown by the different standards set up by various observers. A comparison of the following Table, embodying the standards of Miquel and Macé, shows what contradictory conclusions would be drawn by analysts adopting the respective standards.

| | Miquel.<br>Per c.c. | Macé.<br>Per c.c. |
|---|---|---|
| Very pure water . . . . | 0 to 10 | 0 to 10 |
| Very good water . . . . | 10 to 100 | 20 to 100 |
| Good or pure water . . . | 100 to 1,000 | 100 to 200 |
| Passable water . . . . | 1,000 to 10,000 | 200 to 500 |
| Impure water . . . . | 10,000 to 100,000 | 500 to 1,000 |
| Very impure water . . . | Over 100,000 | 1,000 and upwards. |

Both agree that waters containing less than 200 bacteria per c.c. are of good quality, but above this number their standards are hopelessly at variance. What Miquel would regard as a pure water, Macé would consider as impure and approaching the very impure.

Obviously these standards are absurd, as it is the quality and not the quantity of bacteria present which alone can help us to form an opinion with reference to the safety, or otherwise, of water from a given source. I say 'help' deliberately, as the most satisfactory results, both quantitative and qualitative, may be obtained from a water the source of which may be liable to dangerous contamination, and therefore the most satisfactory result obtained upon bacteriological examination does not in itself enable us to certify a water as safe, but it will aid us in coming to a correct conclusion if the particulars of the source from which the water is obtained are known. Of course, there are occasions when a bacterioscopic analysis may indicate some hidden and previously unsuspected source of danger. As a rule, such danger is indicated by the variations in the number and character of the bacteria present in a water when samples are taken under different conditions. Such variations are usually most marked and most significant after a heavy rainfall. The bacteriological effect of rainfall upon streams, springs, and wells, and the effect of floods have often to be studied before an opinion can be given upon them as sources of supply. The greater the effect of the rainfall or of floods, the more unsatisfactory is the stream, spring, or well, as a source of water supply ; but if a careful examination of the source shows that this is satisfactory, and if few or no bacteria are found which can be identified as of intestinal origin, any turbidity produced by a heavy rain may be regarded as of a practically harmless character.

Certain deep wells in Essex yield waters containing large numbers of bacteria and occasionally also they contain bacteria of an objectionable type. I and my assistants have made a careful study of these wells, and our first efforts were made to discover the source of the Bacillus coli, and later we endeavoured to ascertain the reason why the bacterial counts were usually so numerous. Certain of the results were published in *Public Health* (April 1910) and the further results are now recorded. The wells referred to are all from 500 to 1000 feet deep, in the open country, and pierced through 300 to 500 feet of London clay. Every possible source of pollution has been excluded by investigation. One well which yielded the worst water bacteriologically was particularly examined. The water was pumped out of the sunk portion of the well so that samples could be obtained from the two bore-tubes. Before this pumping was commenced a sample was taken from the rising main from the well.

The results of the examination were as follows :

| | Bacteria per c.c. On Gelatine | Bacteria per c.c. On Agar |
|---|---|---|
| Water from rising main of well . . . . . | 5310 | 980 |
| Water from No. 1 bore . . . . . . . | 12 | 8 |
| Water from No. 2 bore . . . . . . . | 18 | 12 |

The temperature of the water was from 64·2° F. to 64·5° F. At a later date plates and materials were taken to the pumping station, samples were collected and a portion plated on the spot, and the remainder brought to the laboratory and kept at air-temperature until next day, when another set of plates was made. The interval between the two platings was about eighteen hours.

| | Bacteria per c.c. Plated on spot | | Bacteria per c.c. Plated 18 hours later | |
|---|---|---|---|---|
| | On Gelatine | On Agar | On Gelatine | On Agar |
| From unsterilised tap on pumping main . . | 690 | 258 | Thousands | 1780 |
| From sterilised tap on pumping main . . . | 634 | 234 | ,, | 1500 |
| From water in well obtained by lowering bottle . . | Thousands | 348 | ,, | 900 |

The sterilising of the tap had little effect upon the results, but it will be noted that both with gelatine and agar the results from the sterilised tap were a little lower in the samples plated on the spot than in the samples plated eighteen hours later. The effect of keeping the water eighteen hours before plating was remarkable.

The necessity for sterilising the tap from which water is drawn (if the effect of the tap is to be excluded) was shown from the following results obtained when examining a supply to a private house in which there was a case of typhoid fever. The tap was of large size and thickly coated with a slimy zoogl&oelig;a of bacteria. Reference has been made to this case previously.

| | Colonies per c.c. | | |
|---|---|---|---|
| | On Gelatine | On Agar | B. coli. |
| Tap unsterilised . . . . | 710 | 30 | Present in 20 c.c. |
| Tap sterilised . . . . . | 250 | 5 | Absent in 36 c.c. |

Returning to the effect of keeping water before examination, the following results obtained by Dr. Richmond in my laboratory are interesting :

| — | Temp. at which water was kept | No. of Bacteria per c.c. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | On Gelatine | | | | On Agar | | | |
| | | No. of hours before plating | | | | No. of hours before plating | | | |
| | | 0 | 6 | 12 | 24 | 0 | 6 | 12 | 24 |
| Deep well (1) | 22° C. | 230 | 240 | 105 | 1700 | 84 | 80 | 570 | 3500 |
| | 12° C. | 230 | 114 | 75 | 84 | 84 | 61 | 24 | 136 |
| | 0° C. | 230 | 68 | 64 | 86 | 84 | 44 | 32 | 18 |
| Deep well (2) | 22° C. | 78 | 90 | 210 | 3000 | 7 | 7 | 9 | 3000 |
| | 12° C. | 78 | 44 | 56 | 34 | 4 | 4 | 2 | 3<br>(18 h.) |
| Deep well (3) | 22° C. | ? | 640 | 200 | 3600 | ? | 800 | 2610 | 3400 |
| | 12° C. | ? | 640 | 760 | 760 | ? | 800 | — | 350 |

There are curious inconsistencies in the above, but the results show to what an extraordinary extent bacteria may multiply within twenty-four hours, yet during the first six or twelve hours there may be an actual decrease.

When examining a series of deep wells last year samples of the water were collected for bacteriological examination in ½-litre wide-mouthed bottles. From each bottle a small tube of about 20 c.c. capacity was filled and both were packed in ice, and next day they were examined.

The results were as under:

| — | Bottle Samples | | Tube Samples | |
|---|---|---|---|---|
| | Colonies per c.c. | | | |
| | On Gelatine | On Agar | On Gelatine | On Agar |
| Well No. 1 | 9,600 | 1,640 | 1420 | 202 |
| 2 | 3,840 | 1,660 | liq. | 154 |
| 3 | 4,000 | 148 | 1420 | 542 |
| 4 | 94,000 | 48,000 | 6100 | 3700 |
| 5 | 11,520 | 5,400 | 5400 | 3000 |
| 6 | 1,600 | 138 | 490 | 95 |
| 7 | 1,520 | 1,540 | 1500 | 430 |

Speaking generally, the number of bacteria in the water in the small tubes, in which it would be cooled down quickly, was much lower than in the bottles, the water in which would require a longer time to cool down to near 0° C.

Upon another occasion a day was spent at one of these pumping stations collecting samples at intervals and plating them on the spot. The results varied enormously, but, speaking generally, the water gradually improved as pumping continued.

| | Bacteria per c.c. | |
|---|---|---|
| | On Gelatine | On Agar |
| Lowest (at termination of pumping) | 219 | 190 |
| Highest (pumping just commenced) | 4000 | 1270 |

When all these points are considered, together with the fact that the number of bacteria varies enormously in water from the same well, taken on different days and at different times, it is obvious that the enumeration of the bacteria from such wells is of no value whatever. It must be remembered, however, that this refers only to deep wells yielding water of a temperature of about 16° C. In other wells I have never had any reason to suspect any such variation.

We examine monthly samples from many deep-well supplies which invariably contain very few bacteria, although twenty-four hours or more intervene between the taking of the samples and their receipt at the laboratory. In these cases, if any marked increase in the number of bacteria was observed, inquiry would be made to ascertain the cause.

Other investigators have noted that in pure waters and well-filtered waters there is often a rapid increase in the number of bacteria within twenty-four hours, and probably this explains why waters taken from taps in a town often contain far more bacteria than the filtered water which supplies the mains. The water in filtered water reservoirs may contain less than 100 bacteria per c.c., yet when delivered to the consumers it may contain ten times as many. Whipple examined thirteen samples of water from sources not defined, and kept them at temperatures ranging from 2·4° to 23° C. and found a slight increase in the number of bacteria in three and six hours, and a marked increase in twenty-four hours, and at all temperatures an enormous increase in forty-eight hours. He also found that there was greater multiplication in the waters in bottles which were only partially filled than in those which were completely filled, and that there was far less increase in waters kept in large bottles than in waters stored in small bottles. Others have stated that there is less increase in waters kept in stoppered bottles than in bottles plugged with cotton wool.

Besides the variation due to keeping, samples from the same bottle may give varying numbers, doubtless due to the bacteria forming zooglœa-like masses. These minute masses are sometimes visible to the naked eye, and can be isolated and examined. Most vigorous shaking fails to disintegrate them entirely. One sample of water examined before and after shaking gave 860 bacteria per c.c. from the unshaken sample, and 4800 from the same water after very vigorous agitation.

Enough has been said to show how little confidence can be placed in the mere enumeration of the bacteria in a sample of water, whether the bacteria are cultivated on gelatine at 20° C. or on agar at 37° C. Fortunately the number of objectionable bacteria present in water, and for which special search is made, does not vary to any appreciable extent in the usual interval between collection of the water and its examination, as will be shown later.

**2. Search for Special Organisms or Groups of Organisms.** (*a*) *Organisms of Intestinal Type.*—As we have already seen, the isolation and identification of organisms of intestinal origin are in the great majority of cases far more important than the mere determination of the number of microbes in a water. The organisms invariably selected for isolation and identification are (1) the Bacillus coli, (2) the Bacillus enteritidis sporogenes of Klein, and (3) streptococci. These bacteria are found in all sewages and manured soils. The Bacillus coli, which is typical of the coli groups, is undoubtedly a widely distributed organism, and is said to be abundant everywhere. It is certainly found in the excrement of human beings in enormous numbers, as well as in the excrement of other mammals and birds. As it is capable of multiplying outside the body of an animal, it is obvious that it must be a common constituent of road dust, and may be conveyed by such dust and be deposited in reservoirs, cisterns, and other receptacles for water, and be found in and upon everything which such dust can reach. Notwithstanding this, its vitality outside the body is not great. In dark damp places it may multiply for a time, but under less favourable conditions it does not survive long. Even in soil it is unable to compete with the normal bacteria, and in water it only survives for a limited period.

It is contained in all samples of sewage in great numbers (100,000 to 1,000,000 per c.c.), and in a sewage specifically infected with the typhoid bacillus it would be relatively far more abundant than the latter organism. It is also believed that the Bacillus coli communis is far more resistant than the Bacillus typhosus, and, therefore, that a water containing very few or none of the former cannot contain any of the latter. The experiments made by Majors Firth and Horrocks, and recorded in the *British Medical Journal*, September 27, 1902 ('On the Influence of Soil, &c., on Enteric Fever'), tend, however, to show that the

Bacillus typhosus is more resistant than is usually supposed. These observers found that it lived as well in virgin soil as in sewage-polluted soil, and they succeeded in recovering it from the soil seventy-four days after inoculation. In dry sand, however, it only survived twenty-four days, and in peaty soil it did not live so long.

It is quite possible that under certain unknown conditions the Bacillus typhosus may survive, or even multiply, in water, even after the disappearance of the Bacillus coli communis; but the evidence of experience certainly tends strongly to prove that such conditions rarely, if ever, occur in nature; hence, until the opposite is proved, we may continue to regard the absence of the Bacillus coli from a water as indicating the absence of the Bacillus typhosus also.

Unfortunately, much that has been written with reference to the presence of the Bacillus coli in water has no importance, since observers have so often failed to describe the processes they employed, and the characteristics of the bacterium which they have regarded as the Bacillus coli. In other cases the descriptions given show, beyond doubt, that more than one organism has been regarded as the Bacillus coli. By some described processes not more than a few thousands of the Bacillus coli can be demonstrated in a cubic centimetre of crude sewage, whereas by others hundreds of thousands are indicated. Moreover, there are certainly several types of this organism, and whilst some apparently regard all as varieties of the Bacillus coli, others regard them as distinct species, and restrict that name to one particular form.

It is obvious therefore that, to avoid further confusion, some classification should be adopted, the name Bacillus coli being restricted to an organism or group of organisms having certain very precise characteristics. It is now generally agreed that there is a fairly well-defined group of bacilli, the members of which have the following characters in common.

1. They ferment glucose in the presence of sodium taurocholate with the production of acid and gas.

2. They ferment lactose under the same conditions.

3. They also possess one or more of the following characteristics: (*a*) Producing acid and clot in milk; (*b*) producing indol in peptone water.

4. They grow readily on gelatine without liquefying it and—

5. Do not stain by Gram's method.

Bacilli answering to the above description may be said to belong to the B. coli group. Belonging to this group is a bacillus usually spoken of as the B. coli communis, the identification of which is often regarded as important. Klein (' Sewage Microbes in Oysters and other Shell-fish,' 1905) says: ' The culture tests for B. coli communis of fæcal matter of man and of ordinary domestic sewage are these:

' 1. B. coli communis forms on Drygalski medium at 37° C. after 24–36 hours, colonies several millimetres in size, distinctly red, with distinct red halo when viewed in transmitted light.

' 2. In ordinary nutrient gelatine-shake culture, it forms colonies all through the medium with numerous gas bubbles already in 24 hours at 20° C.; in gelatine streak it forms at 20° C. a rapidly spreading dry band with irregular margin; no liquefaction of gelatine at any time.

' 3. Neutral red broth at 37° C. is changed in 24 to 36 hours from cherry red to greenish fluorescent.

' 4. It turns MacConkey fluid (litmus, glucose, taurocholate of soda, peptone) red, forming acid with numerous gas bubbles.

' 5. It grows well in plenol broth at 37° C., making it turbid in 24 hours with copious gas formation.

' 6. It produces indol in nutrient broth at 37° C. in 3–5 days.

' 7. It turns lactose peptone litmus in 24–36 hours at 37° C. red (acid production) with copious gas formation.

' 8. Litmus milk at 37° C. becomes red in 24 hours, due to acid production, the milk becoming clotted in 1–3 days.'

Other bacteriologists do not consider many of these characteristics as being either constant or essential. Boyce defined the B. coli communis as a group of organisms with the following characteristics :

1. They are non-sporing and non-liquefying.
2. They rarely stain by Gram's method.
3. They produce both acid and gas with both glucose and lactose, and may do so with saccharose
4. They produce acid in milk, and usually also coagulate it.
5. They produce acid and gas in bile-salt glucose broth.
6. They grow well at a temperature of 42° C.

It will be observed that he laid no stress on the motility or otherwise of the bacillus, nor on the production of fluorescence in neutral-red media, nor on the production of indol, nor on the formation of clot in milk.

The two definitions given show to what an extent bacteriologists differ, and the serious nature of the difference and its effect in the interpretation of the results of the bacterioscopic examination of water is very evident, if we accept as correct the following opinion expressed by Klein (*British Medical Journal*, Feb. 21, 1903, 'The Bacterioscopic Diagnosis of Sewage Pollution of Shell-fish'). In this paper Dr. Klein says :

'The detection, therefore, of the presence of coli-like bacilli bearing no near resemblance to B. coli communis does not permit any definite expression of opinion as to the probable or even possible derivation from sewage, or as to probable pollution with filth, of the material from which such microbe has been isolated. It is different, however, with the microbe above referred to in detail as B. coli communis, that is, the typical B. coli. As to this micro-organism, it is known for certain that its common habitat is the bowels of man and of the high animals, and that domestic sewage and excremental matter and everything directly or indirectly polluted with these matters contain the B. coli communis, that is, the typical B. coli. In domestic sewage this microbe is present to the extent of 100,000 to 800,000 per 1 c.c. of the sewage, and Dr. Houston and myself have shown that sewage added to sterile water in such small quantities as to defy chemical analysis, is readily detected by the bacterioscopic test—namely, the detection of B. coli communis.

'To summarise, then, the foregoing, the following propositions hold good:

'1. The circumstance that a microbe shows the characters common to all groups of the coli tribe does not suffice to identify it for useful purposes. For proof that it is B. coli communis, or that it belongs to the group of B. Gaertner or B. typhosus group, it has to comply with the several tests agreed by all observers as characteristic of one or other of these groups.

'2. The fact that a microbe, owing to insufficient response to certain presented tests, can only be described as a coli-like microbe, is at present of indeterminate value in making a definite diagnosis of sewage or other pollution.

'3. B. coli communis is a microbe which has its habitat in bowel discharges, that is, excremental matters, and is contained therein in enormous numbers; its presence, therefore, in any material in appreciable and relatively large amounts is highly suggestive of sewage and excremental pollution.'

Obviously, therefore, Klein would not consider all the organisms included in Dr. Boyce's definition as being the typical B. coli, and to him the presence of such in a water would be without significance. Moreover, it will be observed that Klein does not regard the mere detection of the B. coli communis, as defined by himself, as being absolute proof of contamination; he merely asserts that its presence in 'appreciable and relatively large amounts' is 'highly suggestive of sewage and excremental pollution.' This is a most important qualification, and ignorance of it, or a disbelief in its truth, has led many analysts to condemn waters free from any trace of sewage pollution.

Whilst bacteriologists differ amongst themselves as to what organism they regard as the B. coli communis, and again as to the conclusion to be drawn from its presence, it is not likely that anyone aware of these facts can have much confidence in opinions based merely upon the detection of some organism said to be the B. coli communis, even if in the opinion of the analyst they are 'present in appreciable and relatively large amounts.'

Dr. Houston, in his reports to the Metropolitan Water Board, refers to the Bacillus coli communis as a 'flaginac' bacillus, because it produces fluorescence in neutral-red broth, acid and gas in lactose broth, indol in peptone water, and acid and clot in milk.

In his report dated January 1907, p. 47, he says: 'Practically speaking, a flaginac B. coli is a B. coli indistinguishable, according to the tests used, from the typical B. coli of excremental matter. In the great majority of cases, a glucose fermenting coli-like microbe will also produce fluorescence in neutral-red broth cultures. Further, lactose fermenting coli-like microbes nearly always clot milk. There is, therefore, justification for omitting the neutral-red broth and litmus milk tests, and relying solely on the lactose-peptone and the indol tests.

'Practically, in the case of the London waters, an "agin" B. coli may be regarded as presumably a "flaginac" Bacillus coli.'

Houston also refers to a 'sagin' B. coli, which is one that ferments saccharose as well as lactose and glucose.

Houston's experience with the London waters is entirely corroborated by my experience with waters from the most diverse sources. Waters in which the 'flaginac' coli is found, invariably contain other bacteria of the coli group, and in a sewage-polluted water the true B. coli can always be detected, if a few colonies isolated from the growth in lactose broth are carefully examined. I lay no stress upon motility, liquefaction of gelatine, or the production of fluorescence, since we have found it quite superfluous to try these tests when a bacillus conformed to the following requirements:

1. Will grow in twenty-four hours in bile-salt glucose broth with the production of acid and gas.
2. Will grow in twenty-four to forty-eight hours in bile-salt lactose broth with production of acid and gas.
3. Will grow on neutral-red agar producing red colonies, with a more or less defined halo around.

4. Will produce indol in peptone water.
5. Will produce acid and clot in milk in three days.

Such a bacillus may be ‘ flaginac,’ ‘ saginac ’ or ‘ aginac,’ as shown on the chart. I do not regard the ‘ sagin ’ or ‘ agin ’ groups as true coli. There is no doubt, however, that in any water containing members of the ‘ sagin ’ or ‘ agin ’ groups, members of the typical groups will be discovered if a sufficiently large quantity of water is used.

The following Tables compiled from the examination of a number of samples of sewage and of sewage-polluted water, made by Dr. Sowden in my laboratory, show to what extent the different bacteria of the coli group vary in character.

### TABLE I

ORGANISMS GIVING ALL THE REACTIONS OF THE BACILLUS COLI, TAKEN FROM 10 SAMPLES OF SEWAGE, AND 36 SAMPLES OF POTABLE WATER.

| | No. of times found in Sewage | Lactose broth | | Milk | | Glucose with neutral red | | Gelatine | Indol | Motility | No. of times found in Water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Acid | Gas | Acid | Curd | Gas | Fluor. | Liquefaction | | | |
| A | 10 | + | + | + | + | + | + | − | + | + | 12 |
| A′ | 10 | + | + | + | + | + | − | − | + | + | 16 |

### TABLE II

Closely allied motile organisms found in the same samples

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 0 | + | + | + | − | + | + | − | + | + | 1 |
| B′ | 0 | + | + | + | − | + | − | − | + | + | 4 |
| C | 0 | + | + | + | + | + | − | − | − | + | 3 |
| D | 0 | + | + | + | − | + | − | − | − | + | 2 |
| E | 1 | + | + | + | + | + | − | + | + | + | 0 |
| E′ | 1 | + | + | + | + | + | + | + | + | + | 0 |
| F | 1 | + | + | + | + | + | + | + | − | + | 0 |
| G | 1 | + | + | + | D | + | + | + | + | + | 0 |

## TABLE III

Closely allied non-motile organisms found in the same samples

| | No. of times found in Sewage | Lactose broth | | Milk | | Glucose with neutral red | | Gelatine | Indol | Motility | No of times found in Water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Acid | Gas | Acid | Curd | Gas | Fluor. | Liquefaction | | | |
| H | 5 | + | + | + | + | + | + | − | + | − | 7 |
| H′ | 5 | + | + | + | + | + | − | − | + | − | 7 |
| J | 1 | + | + | + | + | + | + | − | − | − | 0 |
| J′ | 0 | + | + | + | + | + | − | − | − | − | 1 |
| K | 0 | + | + | + | + | + | + | + | − | − | 1 |

## TABLE IV

## ORGANISMS OF INTESTINAL TYPE, FERMENTING GLUCOSE AND LACTOSE

### Action on Dulcite, Mannite, and Sucrose

| No. of times found in Sewage | Dulcite | | Mannite | | Sucrose | | Milk | Glucose n. red broth | | Gelatine | Indol | Motility | Gram's Stain | No. of times found in Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acid | Gas | Acid | Gas | Acid | Gas | Coag. | Gas | Fluor. | liquefied | | | | |
| 2 | | | | | + | + | + | + | − | − | + | + | | 0 |
| 1 | | | | | + | + | + | + | + | − | + | − | | 0 |
| 0 | | | | | − | − | + | + | − | − | + | + | | 1 |
| 0 | | | | | − | − | + | + | + | − | − | + | | 1 |
| 1 | | | | | − | − | + | + | + | − | − | − | | 0 |
| 0 | − | − | + | + | − | − | + | + | − | − | + | + | − | 1 |
| 0 | + | + | + | + | + | + | + | + | − | − | + | + | − | 1 |
| 2 | + | + | + | + | − | − | + | + | − | − | + | + | − | 3 |
| 0 | − | − | + | + | + | + | + | + | − | − | + | + | − | 2 |
| 2 | + | + | + | + | ? | − | + | + | + | − | + | + | − | 3 |
| 1 | − | − | + | + | + | + | + | + | + | − | + | + | − | 2 |
| 1 | + | + | + | + | + | + | + | + | + | − | + | + | − | 1 |
| 0 | + | + | + | + | − | − | + | + | − | − | + | − | − | 4 |
| 4 | − | − | + | + | − | − | + | + | − | − | + | − | − | 3 |
| 1 | + | + | + | + | − | − | + | + | + | − | + | − | − | 0 |
| 1 | − | − | + | + | − | − | + | + | + | − | + | − | − | 3 |
| 0 | − | − | + | + | + | + | + | + | + | − | + | − | − | 4 |

## TABLE V

## ORGANISMS OF INTESTINAL TYPE CLASSIFIED ACCORDING TO THE PRODUCTION OF FLUORESCENCE AND LIQUEFACTION OF GELATINE, FROM 9 SAMPLES OF SEWAGE AND 17 SAMPLES OF WATER.

### 1. Neither liquefying gelatine nor producing fluorescence in neutral red.

| No. of times found in Sewage | Lactose | | Dulcite | | Mannite | | Sucrose | | Coagulation of Milk | Liquefaction of Gelatine | Indol | Motility | Gram's Stain | Fluorescence | No. of times found in Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acid | Gas | Acid | Gas | Acid | Gas | Acid | Gas | | | | | | | |
| 2 | + | + | | | | | + | + | + | − | + | + | | − | 0 |
| 3 | + | + | | | | | | | + | − | + | + | | − | 3 |
| 4 | + | + | | | | | | | + | − | + | +? | | − | 0 |
| 0 | + | + | | | | | − | − | + | − | + | + | | − | 1 |
| 4 | + | + | − | − | + | + | − | − | + | − | + | +? | − | − | 4 |
| 0 | + | + | + | + | + | + | + | + | + | − | + | + | | − | 1 |
| 2 | + | + | + | + | + | + | − | − | + | − | + | +? | − | − | 7 |
| 0 | + | + | − | − | + | + | + | + | + | − | + | + | − | − | 2 |

### 2. Not liquefying gelatine but producing fluorescence.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | + | + | | | | | + | + | + | − | + | − | | + | 0 |
| 1 | + | + | | | | | − | − | + | − | − | − | | + | 0 |
| 8 | + | + | | | | | | | + | − | + | +? | | + | 0 |
| 0 | + | + | | | | | − | − | + | − | + | + | | + | 1 |
| 3 | + | + | + | + | + | + | + | − | + | − | + | +? | − | + | 3 |
| 1 | + | + | − | − | + | + | − | − | + | − | + | − | − | + | 3 |
| 1 | + | + | − | − | + | + | + | + | + | − | + | +? | − | + | 6 |
| 1 | + | + | + | + | + | + | + | + | + | − | + | + | − | + | 1 |

### 3. Lactose fermenters, liquefying gelatine.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | + | + | | | | | | | + | + | + | + | | − | 0 |
| 1 | + | + | | | | | | | + | + | − | + | | + | 0 |
| 1 | + | + | | | | | | | + | + | + | + | | + | 0 |
| 1 | + | + | + | + | + | + | + | + | digested | + | + | + | | + | 0 |
| 0 | + | + | − | − | + | + | − | − | + | + | − | − | | + | 1 |

### 4. Non-lactose fermenters, producing fluorescence.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | − | − | | | | | + | + | + digested | + | + | + | | + | 0 |
| 1 | − | − | | | | | | | + digested | + | + | + | | + | 0 |
| 0 | − | − | − | − | + | + | + | − | + digested | + | − | + | − | + | 1 |

The following experiments are of paramount interest, as it is upon the results of these and others of a similar character that my method of examination of water to detect evidence of sewage contamination is based.

The bacteria found in nine samples of sewage and thirty-six samples of water were examined, and all those found capable of fermenting glucose and lactose in a bile-salt medium were picked out, and the result of their further examination is tabulated below.

ORGANISMS FERMENTING GLUCOSE AND LACTOSE AND PRODUCING RED COLONIES ON BILE-SALT, AGAR, NEUTRAL-RED MEDIA

ISOLATED FROM 9 SEWAGES AND 36 WATERS

| Group to which organism belongs | No. of times found in Sewage | Milk | | Glucose neutral-red agar | | Gelatine. Liquefaction. | Indol | Motility | No. of times found in Water |
|---|---|---|---|---|---|---|---|---|---|
| The coli groups: | | Acid | Curd | Gas | Fluor. | | | | |
| A | all | + | + | + | + | − | + | + | 12 |
| A′ | ,, | + | + | + | − | − | + | + | 16 |
| B | 0 | + | + | + | − | − | − | + | 3 |
| B′ | 0 | + | − | + | + | − | + | + | 1 |
| B″ | 0 | + | − | + | − | − | + | + | 4 |
| C | 0 | + | − | + | − | − | − | + | 2 |
| B. lactis aërogenes group | 5 | + | + | + | + | − | + | − | 7 |
| ,, | 5 | + | + | + | − | − | + | − | 7 |
| ,, | 1 | + | + | + | + | − | − | − | 0 |
| ,, | 0 | + | + | + | − | − | − | − | 1 |
| Liquefy gelatine. Proteus group | 0 | + | + | + | − | + | + | + | 0 |
| ,, | 1 | + | + | + | + | + | − | + | 0 |
| ,, | 1 | + | + | + | + | + | + | + | 0 |
| ,, | 1 | +digested | | + | + | + | + | + | 0 |
| ,, | 1 | + | + | + | + | + | − | − | 1 |

None of the organisms retained Gram's stain.

The members of the Bacillus coli group 'A' were alone found in every sample of sewage and of polluted water. The next in order of frequency were the members of the B. lactis aërogenes group, which corresponded with the B. coli group 'A' in all respects save that of motility. That organisms capable of liquefying gelatine should be so rarely found is probably due to the selective action of the bile-salt medium.

The important point is that in every sample of sewage and in every sample of water which there were reasons for believing were sewage-polluted, bacteria capable of fermenting lactose and glucose, of producing acid and clot in milk and of producing indol in peptone water, were discovered.

At a later date a tap water, to which $\frac{1}{100,000}$ part of sewage had been added, was examined. Three neutral-red agar plates were made from 1 c.c. of the water, and twelve different colonies of a red colour were picked off and examined with various sugar and other media. The results were as under :

| No. | Litmus lactose broth | | Litmus dulcite broth | | Litmus mannite broth | | Litmus sucrose broth | | Milk | | Indol | Neutral-red agar. Fluorescence | Motility | Gram | Gelatine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acid | Gas | Acid | Gas | Acid | Gas | Acid | Gas | Acid | Clot | | | | | |
| 1 | + | + | + | + | + | + | − | − | + | + | + | + | + | − | − |
| 2 | + | + | − | − | + | + | − | − | + | + | + | − | − | | − |
| 3 | + | + | − | − | + | + | − | − | + | + | + | + | − | | − |
| 4 | + | + | − | − | + | + | − | − | + | + | + | − | − | | − |
| 5 | + | + | − | − | + | + | + | + | + | + | + | + | + | | − |
| 6 | + | + | + | + | + | + | + | + | + | + | + | + | + | | − |
| 7 | + | + | − | − | + | + | + | + | + | + | + | + | − | − | − |
| 8 | + | + | − | − | + | + | + | + | + | + | + | − | + | | − |
| 9 | + | + | − | − | + | + | − | − | + | + | + | + | − | − | |
| 10 | + | + | − | − | + | + | + | + | + | + | + | + | + | | + |
| 11 | + | + | | | | | + | + | + | + | + | − | + | | − |
| 12 | + | + | | | | | − | − | + | + | + | + | − | | − |

It will be noted that practically the whole differed in some respect, but that all fermented lactose, all produced acid and clot in milk, eleven out of the twelve produced indol.

All the ten examined fermented mannite, but only 50 per cent. fermented sucrose, 20 per cent. dulcite, about 70 per cent. produced fluorescence on neutral-red agar, 50 per cent. were motile, and only 1 out of 11 liquefied gelatine.

The non-motile bacteria may be regarded as belonging to the lactose aërogenes group, and those liquefying gelatine to the proteus group. But the latter groups are almost as characteristic of sewage or of decomposing animal matter as the B. coli group, hence all these could be regarded as bacteria of an 'intestinal type.'

I now regard all bacteria which are capable of fermenting glucose and lactose in a bile-salt broth as being of this type, and if further examination shows that any of the isolated bacteria also produce acid and clot in milk, and indol in peptone water, I regard them as belonging to the coli group and call them colon bacilli. My experience is that whenever these bacilli are detected, some of them will be found which are motile and which do not liquefy gelatine, and which may therefore be said to belong to the true B. coli group.

This also appears to be Houston's conclusion from the examination of the London waters, as he no longer makes reference to motility or the effect of Gram's stain, and apparently he regards flaginac, saginac, aginac, sagin and agin bacilli as of equal significance. Whenever one type is found, others will be detected if search is made, and future experience may demonstrate that the best test for sewage pollution is the discovery of bacteria of more than one type. Any one species may obtain accidental access to a water and be of little or no significance, but where bacilli of these varying types are found sewage pollution would be practically certain.

The accompanying chart shows Houston's classification.

I should not regard the sagin and agin bacilli as belonging to the colon group, and regard their presence as having a minor significance, unless associated with one of the other groups, when the association would leave little doubt as to their common origin from sewage or manurial matter.

The so-called B. coli is certainly a 'group,' and not a definite species, as, by the use of dulcite, mannite, sucrose, and other sugars and neutral-red solutions, a further differentiation can be effected. At present no useful purpose would be served by defining further the members of this group, and the classification adopted is merely for convenience in explaining the steps in the process to be described later for the bacteriological examination of

## CLASSIFICATION OF BACTERIA OF INTESTINAL TYPE

Producing Acid and Gas in Lactose Bile-salt Broth

- Red Colonies produced with haze around on Neutral-red Bile-salt Lactose Agar plates
- White Colonies. Not belonging to the Coli group

| | | | | | | |
|---|---|---|---|---|---|---|
| (a) *Neutral-red Broth.* | Fluorescence | ? | ? | ? | ? | ? |
| (b) *Peptone Solution.* | Indol | Indol | Indol | Indol | Indol | No Indol |
| (c) *Litmus Milk.* | Acid and Clot | Acid and Clot | Acid and Clot | Acid. No Clot | Acid. No Clot | Acid. No Clot |
| (d) *Saccharose Broth.* | No Gas | Acid and Gas | No Gas | Acid and Gas | No Gas | No Gas |
| | Houston's | Houston's | Houston's | Houston's | Houston's | Not regarded |
| | 'Flaginac' B. Coli | 'Saginac' B. Coli | 'Aginac' B. Coli | 'Sagin' B. Coli | 'Agin' B. Coli | as a B. Coli. |

water, and for the prevention of any misconception in the discussion on the interpretation of the results.

The bacteria of the colon group are found in large numbers in all sewage, and are those for which a special search should be made in the bacteriological examination of drinking waters. The mere presence of allied forms has, at present, no known significance, as we know little or nothing of their relation to sewage or similar filth ; but in the vast majority of cases where these related bacteria are found in water, careful examination reveals the presence of the typical bacteria of the colon group, if larger quantities of water are taken for examination.

For the last few years I have made a systematic search for the colon bacilli in all waters submitted to me for bacterioscopic examination, and although I have, in the great majority of cases, found that the presence of these organisms was associated with pollution, even when the latter was not indicated by the chemical analysis, I have, on occasions, found them in waters above suspicion of pollution. In one case, the water from a deep well supplying a certain town was found to contain Bacillus coli. Upon examining the sample sent me there was no difficulty in finding it in so small a quantity of the water as one cubic centimetre, but even on using a considerable quantity of the water the Bacillus enteritidis sporogenes, which is always associated with the B. coli communis in sewage, could not be detected. I visited the town, and found the well was perfectly constructed, was in the open country, and was far from any inhabited houses. The water was derived from the chalk, which at this point was covered by 300 to 400 feet of London clay, and the nearest outcrop was twelve miles away. A sample of the water from the rising main was collected, and upon examining it, the colon bacilli were found to be present. Chemically the water was of the highest standard of purity. I have examined several samples of the water since, but without detecting any organism of the coli groups. How the water became infected could not be ascertained, but as I was certain that under the circumstances the presence of the organism had no significance, I certified that, in my opinion, the water was of excellent quality, and free from sewage or manurial pollution.

The examination of this well led me to pay a good deal of attention to the waters from other deep wells, and as I am connected with many public supplies deriving water from such wells, my assistant, Dr. Richmond, undertook a systematic examination of a number of them. One or other of us collected all the samples, examined the construction of the wells, and also examined the surroundings so far as was necessary to ascertain whether there was any risk of pollution.

Fifteen pumping stations with twenty-four wells were examined. These wells vary in depth from 500 to 1000 feet and the water is derived from chalk overlaid by London clay not less than 300 feet in thickness. All the wells are of the most modern type of construction, and pollution by sewage matter is impossible.

Various quantities of each water were first added to bile-salt glucose broth and incubated for not less than twenty-four hours. If the liquid became acid and gas was being formed, the sample was said to give positive results with the 'presumptive' test in the quantity of water used. When the presumptive test was positive, a loop full of the broth was added to bile-salt lactose broth and the inoculated liquid incubated. If acid and gas were produced, the water was said to give positive results with the 'confirmatory' test. From each of the fermenting tubes neutral-red agar plates were made, and red colonies (usually three) picked off and used for the final tests. If these gave positive results, the B. coli was taken to be present.

Five of the well-waters gave no response to the 'presumptive' test, the other sixteen gave the results tabulated on p. 214. The quantities of water used were 1, 5, 10 and 20 c.c.

It will be noted that no less than four of these wells yielded water containing the B. coli, which answered every one of the requirements of Drs. Klein and Houston. Every water which gave the 'confirmatory' reaction proved to contain bacteria of the colon group in the quantity of water required to give this reaction. This is not always the case. Many waters answer

| — | B Coli. Smallest quantity of Water giving— | | |
|---|---|---|---|
| | Presumptive Test | Confirmatory Test | Conclusive Tests |
| 1 . . . | 20 c.c. | — | — |
| 2 . . . | 5 ,, | — | — |
| 3 . . . | 5 ,, | — | — |
| 4 . . . | 1 ,, | 1 c.c. | 1 c.c. |
| 5 . . . | 1 ,, | — | — |
| 6 . . . | 5 ,, | — | — |
| 7 . . . | 20 ,, | — | — |
| 8 . . . | 5 ,, | — | — |
| 9 . . . | 5 ,, | 5 c.c. | 5 c.c. |
| 10 . . . | 5 ,, | 5 ,, | 5 ,, |
| 11 . . . | 1 ,, | — | — |
| 12 . . . | 5 ,, | — | — |
| 13 . . . | 10 ,, | — | — |
| 14 . . . | 1 ,, | — | — |
| 15 . . . | 5 ,, | — | — |
| [1]16 . . . | 5 ,, | 5 c.c. | 5 c.c. |

the 'confirmatory' test with, say, 5 c.c. of water, but do not contain B. coli in that quantity. Almost invariably in such cases the examination of a larger quantity of water reveals the presence of the Bacillus coli. This subject is referred to later.

A curious fact was noted as the result of these inquiries, namely, that the four wells which yielded the water containing the colon bacilli were the only wells which were completely covered at the ground-level, and it was thought that the removal of the covers might cause the organisms to disappear. A year after the removal of these covers, the samples of water examined were found free from the B. coli; but, unfortunately, recent examinations have shown the presence of the colon bacilli in both these and other wells.

The well which yielded the B. coli in 1 c.c. was selected for special examination. In order to understand what follows, a description of the well must be given. At the top it is 9 feet in diameter, and it is sunk this width to a depth of 400 feet. From the bottom there are two bores lined with steel tubes which go down a further 600 feet, so that all the water entering the well comes from a depth of about 1000 feet. When pumping, the water-level is some 350 feet from the ground surface, and in order to raise the water to the reservoir it is twice pumped. The first pump raises the water to a tank fixed in the well on a staging, at a depth of about 125 feet. From this tank the second pump raises it to the reservoir. The inside of the well was examined and found in perfect condition, yet the water, raised to the surface, continued to show the presence of B. coli in from 1 to 5 c.c. A little later a few streptococci were found, and still later the spores of Bacillus enteritidis sporogenes were detected in 100 c.c., but on no occasion have all these been found in the water at one and the same time.

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[1] In June 1912 I personally collected samples from twenty such deep wells, taking the water from the rising mains. Five of these samples contained the B. coli in 20, 10, 10, 20 and 5 c.c. respectively. In two instances, where the wells were within about 100 yards of each other, one contained the B. coli and the other did not.

Arrangements were then made for taking a sample of water from the discharge pipe of the lower pump and from the bottom of the well. We failed to get a sample from the latter, but obtained one from the outlet of the pump into the cistern, and at the same time a sample was taken from the top of the rising main. The difference between the two waters was extraordinary. The water as it reached the first stage contained very few bacteria and no B. coli; that which reached the top of the well contained thousands of bacteria per c.c. and the B. coli in 1 c.c. Next month similar samples were taken, and again there was a difference, though not so marked as before. A few days later the packing of the force-pump in the well was examined and found to be of tallowed hemp having a disagreeable odour and swarming with bacteria, the B. coli being very abundant. Later the water from the lower pump showed the presence of B. coli, and it was then found that at every stroke of the upper pump some ounces of water squirted on to the sides of the well and ran down to the water below. In the water thus ejected through defective joints we found not only the B. coli, but also the spores of B. enteritidis sporogenes or of an allied organism.

Samples were taken at intervals until arrangements could be made for getting at the bore-tubes so as to take samples of water therefrom. This was done in February 1909, and the water found to be of the very highest degree of bacterial purity. Since then the samples examined have been taken from the rising main, and the B. coli is still present, and usually there is an abundance of other bacteria. The inside of the well has been lime-washed, the pump rods have been cleaned and repainted, the packing of the pumps has been changed on several occasions, but all without avail. The water enters the well in a condition of extraordinary purity, it emerges from the well loaded with bacteria, some of which are of the type usually considered to be of intestinal origin.

Many similar instances could be recorded, in some of which the origin of the bacteria of objectionable type could be traced, whilst in others all efforts to trace their origin have failed. The subject is of such great importance that a few other experiences cannot fail to be interesting. The water submitted for examination by an Urban Authority was found to contain B. coli, and we had never previously found it in the water from the deep well supplying this town. I therefore arranged to visit the waterworks, inspect the well, &c. The water is raised by means of an air-lift pump, and unless some small animal had got down the rising main there was no possibility of pollution. Inquiries were made as to the way in which the sample was taken, and the Surveyor admitted that he had sent up a scavenger to take it. The scavenger was found and a bottle given him to fill, in exactly the same way in which he had taken the sample for analysis. He grasped the neck of the bottle with his dirty hand and held the bottle under the outlet of the rising main. The water flowed over his hand into the bottle. Asked if he had not washed his hand prior to filling the bottle, he said that he had not. A sample of the water properly taken contained no objectionable bacteria. About the origin of those in the previous sample there could be no doubt.

In the new red sandstone area a Water Company derives some two to three million gallons of water per day from very deep wells sunk in this stratum. Usually of great bacterial purity, the presence of the B. coli in samples submitted for analysis gave cause for some uneasiness. The number of these increased, and a little later other organisms of intestinal type were discovered. Matters looked very serious indeed, and ultimately an examination of the works was decided upon. I explained to the Directors that it was better to commence with an examination of the wells, but they were so certain that there was no possible source of contamination there, that the sandstone outcrop was first examined, but without result. The wells and immediate surroundings were then inspected. The water from the deep wells was being pumped into a large iron tank beneath the engine-house floor, and from there forced to the various service reservoirs. The water in the tank was covered with dust and the sides were slimy. Samples of water were taken from the rising mains and from the tank. These, when examined, showed that the water as it came from the bore-holes and wells was quite free from the B. coli, whereas after it had passed through the tank it contained this and other bacteria of intestinal type. The tank was emptied and a sample of the deposit sent me. Had its source not been known, I should have regarded it as being obtained from a cesspool or septic tank. It contained not only the B. coli, but also large numbers of streptococci and spores of the Bacillus enteritidis sporogenes. The tank was cleaned out, but for a time the water still contained colon bacilli, but in far smaller number. These gradually disappeared, and for the last two years the water has not been infected by these bacilli. The tank was carefully covered, after being cleaned, but it was not sterilised. This could have been effected by means of a solution of chlorinated lime. Tanks of this character should be carefully covered, and occasionally cleaned and sterilised, otherwise flies or other small animals gain access to the water, a slimy growth or deposit forms, and in or upon this objectionable bacteria multiply.

More recently, the water from deep wells in the chalk furnishing the supply to an extensive and populous district was found to contain B. coli in unusual abundance. Large quantities, when examined, did not show the presence of other bacteria of an intestinal type; but the possibility of sewage contamination could not be ignored, and all the drains, &c., around were tested and, where found defective, put in thorough repair. Instead of the water improving in character it gradually got worse. Finally certain changes, observed as the result of detailed chemical analyses, led me to suspect the infiltration into the chalk of water from a gasometer tank not very far away. A sample of water from this tank was obtained. Upon bacteriological examination it was found to contain in each cubic centimetre thousands of colon bacilli. Save in crude sewage I never found so large a number. No other bacillus of intestinal type appeared to be present. Further investigation showed that the gas-holder was leaking. No doubt the crack had gradually enlarged, admitting to the chalk a continually increasing amount of this coli-infected water. Since the gas-holder was thrown out of use, the water has steadily improved in character. Most fortunately this water was submitted to a softening process before it was distributed, and the purifying effect of the softening was most marked. By paying great attention to the process and allowing the water, to which lime had been added, to stand four hours before being drawn off, a supply of water of good quality was maintained.

The subjoined record of the daily examination of the crude chalk water and of the softened water is not only interesting as showing the effect of the lime on the B. coli, but also as showing that in practically all cases a bacillus which grows in bile-salt lactose broth, with the production of acid and gas, proves on further examination to be a bacillus of the colon group. The improvement in the water chemically is also noteworthy.

During the month in question the well-water contained colon bacilli in from 0·1 c.c. to 60 c.c. In the softened water the B. coli was never found in 60 c.c. and only three times in 100 c.c. A very high standard! The softening also removed over 80 per cent. of the bacteria capable of growing on gelatine in three days, and about 95 per cent. of the bacteria capable of growing at blood-heat. About 40 per cent. also of the organic matter was removed, rendering the softened water usually of the highest degree of organic purity.

# HARD WATER FROM DEEP CHALK WELLS. ALSO THE CORRESPONDING SOFTENED WATER

| Chlorine | Sulphates as $SO_4$ | Albuminoid Ammonia | Oxygen absorbed 4 hrs. at 37° C. | Degrees of Hardness | Bacteria per c.c. Gelatine 20° C. | Bacteria per c.c. Agar 37° C. | B. Coli Tests | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Presumptive | Confirmatory | Decisive |
| 2·5 | 4·2 | ·0056 | ·048 | 30· | 900 | 220 | 1 c.c | 1 c.c. | 1 c.c. |
| 2·5 | — | ·0046 | ·032 | 8· | 460 | 20 | 100 c.c. | —100 c.c. | — |
| 2·5 | 4·1 | ·0050 | ·042 | 29· | 1060 | 240 | 1 c.c. | 5 c.c. | 5 c.c. |
| 2·5 | — | ·0036 | ·035 | 8· | 540 | 4 | —100 c.c. | — | — |
| 2·4 | 4·8 | ·0048 | ·039 | 29· | 1080 | 66 | 1 c.c. | 5 c.c. | 5 c.c. |
| 2·4 | — | ·0032 | ·028 | 8· | 240 | 8 | 100 c.c. | 100 c.c. | 100 c.c. |
| 2·5 | 4·1 | ·0056 | ·045 | 29· | 1760 | 800 | 1 c.c. | 1 c.c. | 1 c.c. |
| 2·4 | — | ·0042 | ·035 | 8· | 98 | 8 | 10 c.c. | 100 c.c. | 100 c.c. |
| 2·4 | 3·8 | ·0076 | ·049 | 29·5 | 880 | 106 | 1 c.c. | 5 c.c. | 5 c.c. |
| 2·3 | — | ·0028 | ·020 | 10·5 | 140 | 24 | 10 c.c. | 100 c.c. | 100 c.c. |
| 2·4 | 3·8 | ·0075 | ·054 | 30· | 940 | 100 | 1 c.c. | 1 c.c. | 1 c.c. |
| 2·4 | — | ·0030 | ·020 | 7·5 | 440 | 20 | —100 c.c. | — | — |
| 2·4 | 3·6 | ·0035 | ·033 | 30· | 1420 | 54 | 1 c.c. | 10 c.c. | 10 c.c. |
| 2·4 | — | ·0010 | ·000 | 8· | 180 | 8 | —100 c.c. | — | — |
| 2·4 | 4·2 | ·0030 | ·000 | 30· | 1100 | 56 | 1 c.c. | 10 c.c. | 10 c.c. |
| 2·4 | — | ·0024 | ·018 | 7·5 | 420 | 24 | —100 c.c. | — | — |
| 2·4 | 4·6 | ·0032 | ·025 | 30· | 5400 | 296 | 1 c.c. | 10 c.c. | 10 c.c. |
| 2·4 | — | ·0018 | ·000 | 8· | 170 | 6 | 100 c.c. | —100 c.c. | — |
| 2·4 | 3·8 | ·0040 | ·026 | 30· | 1240 | 120 | 1 c.c. | 5 c.c. | 5 c.c. |
| 2·4 | — | ·0028 | ·020 | 8· | 160 | 38 | —100 c.c. | — | — |
| 2·4 | 3·6 | ·0020 | ·026 | 30·5 | 860 | 112 | 1·1 c.c. | 1 c.c. | 1 c.c. |
| 2·4 | — | ·0016 | ·032 | 7·5 | 440 | 2 | —100 c.c. | — | — |
| 2·4 | 3·8 | ·0027 | ·012 | 30·5 | 830 | 98 | 1 c.c. | 10 c.c. | 10 c.c. |
| 2·4 | — | ·0018 | ·010 | 7·5 | 184 | 6 | 100 c.c. | —100 c.c. | — |
| 2·2 | 3·6 | ·0028 | ·008 | 30 | 520 | 26 | 20 c.c. | 20 c.c. | 20 c.c. |
| 2·2 | — | ·0044 | ·008 | 8 | 225 | 2 | —100 c.c. | — | — |
| 2·2 | 2·9 | ·0018 | ·004 | 30 | 298 | 8 | 60 c.c. | 60 c.c. | 60 c.c. |
| 2·2 | — | ·0024 | ·008 | 7·5 | 225 | 2 | 60 c.c. | —100 c.c. | — |
| 2·3 | 3·0 | ·0047 | ·008 | 30· | 284 | 8 | 60 c.c. | 60 c.c. | 60 c.c. |
| 2·3 | — | ·0039 | ·008 | 7·5 | 54 | 6 | —100 c.c. | — | — |
| 2·4 | 3·6 | ·0033 | ·020 | 30·5 | 1240 | 80 | 5 c.c. | 10 c.c. | 10 c.c. |
| 2·4 | — | ·0024 | ·012 | 10· | 648 | 8 | 20 c.c. | —100 c.c. | — |
| 2·2 | 3·1 | ·0034 | ·012 | 29·5 | 1084 | 72 | 10 c.c. | 10 c.c. | 10 c.c. |
| 2·2 | — | ·0042 | ·018 | 7·5 | 720 | 16 | —100 c.c. | — | — |
| 2·2 | 4·3 | ·0032 | ·020 | 30· | 880 | 32 | 1 c.c. | 5 c.c. | 5 c.c. |
| 2·2 | — | ·0020 | ·008 | 7·5 | 500 | 14 | —100 c.c. | — | — |
| 2·2 | 3·7 | ·0014 | ·004 | 29·5 | 720 | 18 | 5 c.c. | 10 c.c. | 10 c.c. |
| 2·2 | — | ·0008 | ·000 | 7 | 280 | 4 | —100 c.c. | — | — |
| 2·2 | 3·9 | ·0030 | ·007 | 30 | 540 | 40 | 5 c.c. | 20 c.c. | 20 c.c. |
| 2·2 | — | ·0030 | ·000 | 7·5 | 184 | 6 | —100 c.c. | — | — |
| 2·2 | 3·5 | ·0038 | ·001 | 29 | 506 | 28 | 20 c.c. | 20 c.c. | 20 c.c. |
| 2·2 | — | ·0010 | ·000 | 6·5 | 114 | 6 | —100 c.c. | — | — |
| 2·0 | 4·4 | ·0031 | ·014 | 29·5 | 480 | 12 | 60 c.c. | 60 c.c. | 60 c.c. |
| 2·0 | — | ·0026 | ·004 | 9·5 | 340 | 4 | —100 c.c. | — | — |
| 2·3 | 3·1 | ·0030 | ·0013 | 29·5 | 500 | 44 | 5 c.c. | 10 c.c. | 10 c.c. |
| 2·3 | — | ·0052 | ·001 | 7·5 | 116 | 12 | —100 c.c. | — | — |
| 2·3 | 3·2 | ·0024 | ·001 | 30 | 740 | 31 | 5 c.c. | 5 c.c. | 5 c.c. |
| 2·3 | — | ·0020 | ·001 | 7·5 | 170 | 12 | —100 c.c. | — | — |

As a rule, softened water varies greatly in its bacterial contents, but there is no doubt that if the softening process is a suitable one, and is carried on under skilled supervision, a remarkable purifying effect results from the action of the lime.

In another case the water supply to a town was reported by the analyst to be polluted, and the Medical Officer of Health recommended the Town Council to close the works and avail themselves of another, temporarily, available source of supply. This was done, and I then examined the disused works. The water was derived from a bed of superficial gravel, and rose through the gravel bottom of a large collecting reservoir. There were houses and sewers near, but on the result of the examination and certain tests made with fluorescin I concluded that the pollution was not from this source. The reservoir water was of great organic purity, but it contained thousands of bacteria per cubic centimetre and the colon bacilli in so small a quantity as 1 c.c. The reservoir was emptied and the bottom examined.

Where the water rose most freely, samples collected proved to be of great bacteriological purity, but a sample collected at a point near the boundary wall, where the bottom seemed slightly discoloured, proved to be loaded with bacteria and to contain colon bacilli in abundance.

A little solution of fluorescin was poured into a hole (made with a walking-stick) in the soil outside the tank, at a point near where the polluted water entered.

Within half an hour the fluorescin appeared in the reservoir. The soil here was very porous and, when examined, it was found to be grossly contaminated. The origin of the pollution was now obvious. The reservoir is covered with a semicircular roof of galvanised iron. During dry weather it was nearly covered with bird droppings.

After a heavy rainfall the whole of this filth was washed on to the porous ground at the edge of the reservoir and percolated quickly into the water supply. Since cleaning the tank and concreting and troughing around, the water has become perfectly satisfactory, even after heavy rains. There is no doubt that the pollution would have been detected long previously if a sample of water had been collected for analysis after a heavy rainfall.

The above and other experiences demonstrate that whenever the colon bacilli are found in a spring of well-water, a careful examination of the source from which the water is derived, and of all tanks, vessels, &c., with which the water comes in contact, is absolutely necessary.

On the other hand, the absence of the B. coli is no proof that a water is not seriously contaminated, or liable to such pollution. This statement applies more especially to waters from the subsoil and derived from springs or shallow wells. Not a week passes, probably, without some sample being examined in my laboratories which would, from the bacteriological results alone, be pronounced good, whereas the chemical results show that the water is more or less seriously polluted and that it comes from a subsoil markedly affected by manurial matter. Unless the chemical character of a water is known, it is never safe to give an opinion based solely upon the results of a bacteriological examination.

Whenever a water has been polluted by sewage or manurial matter and the pollution is of sufficiently recent date to be dangerous in character, other organisms characteristic of sewage (or manure) besides the Bacillus coli should be found in it.

All these bacteria gradually die out, but unfortunately it is impossible to say which species will disappear first and which last. This is well shown by the results of examinations of mixtures of sewage with pure water, which will be referred to later.

One of these characteristic organisms is a spore-bearing bacillus, the Bacillus enteritidis sporogenes, and others are species of streptococci, which are invariably found in sewage associated with the Bacillus coli.

(*b*) *The Bacillus Enteritidis Sporogenes of Klein.*—This organism was first fully described by Klein, who found it in all sewages, in horse manure, earth from manured fields, &c. He could not detect it in the dung of cows or pigs. Other competent observers appear to find that it is very widely diffused, and assert that it occurs in many places where sewage or manurial contamination is improbable, if not impossible. Klein, however, has recently pointed out that many of these observers are mistaken, since they have confounded some other organism with the true enteritidis sporogenes.

The characteristics of the B. enteritidis sporogenes, as laid down by Klein, are as follows: The bacilli are 0·8μ in thickness, and from 1·6μ to 4·8μ in length, but a few are longer than this, and they may form short chains. There are several long flagella at one or both ends. They readily form spores, which are, at first, glistening globules, generally near one end, but gradually increase in size, becoming oval bodies 1·6μ in length, and as much as 1·0μ or even 1·2μ in thickness. Stained in boiling fuchsin, and then in methyl blue, the spores become coloured dark pink, while the bacillary substance is stained blue. The bacillus is motile, and is an obligatory anaërobe. On solidified serum the growth at 37° C. is copious, and the formation of spores sets in in two to three days, the serum being gradually liquefied. It grows well in agar to which 2 per cent. of grape sugar has been added. In sub-cultures in this medium it rapidly forms copious gas bubbles, by which the agar becomes split up and torn in different directions. It liquefies grape-sugar gelatine, with the formation of gas. The spores do not lose their power to germinate if exposed to 80° C. for fifteen minutes; they are, however, killed if immersed in boiling water for two minutes. Recently boiled milk, inoculated with the spores and incubated at 37° C. in a Buchner's tube, undergoes the following typical changes within twenty-four hours: There is copious gas formation, by which the cream layer is deranged or entirely destroyed, the milk becoming changed into colourless, clear, or slightly turbid whey, on the surface of which accumulate faintly pinkish flocculi of casein; at the bottom and side of the tube are a few casein masses. The whey has an acid reaction and a strong smell of butyric acid. It is found to be swarming with the bacilli, but *these do not, at any time, form spores in milk cultures.* The whey, containing the bacilli, is pathogenic to rodents.

In the report of the Medical Officer to the Local Government Board for the year 1901–2, Dr. Klein gives the results of his experiments on the 'Differentiation of the several anaërobic microbes commonly present in the intestinal contents of man and other animals.' Three microbes are described: the B. enteritidis sporogenes, the B. butyricus (Botkin), and the B. cadaveris sporogenes. The two former, or rather their spores, are usually found associated in sewage and manurial matter and 'are notably present, too, in intestinal discharges of man and animals,' whilst the third occurs normally in the intestines of man and animals, and is the 'principal instrument in the disintegration and dissolution of the viscera of the dead body.' This close association with filth and with decomposing animal matter makes their differentiation a matter of little importance in water analysis, as the presence of any one of them is significant of pollution. Such being the case, it is difficult to understand the following passage which occurs in Klein's report (p. 407): 'It is the association of the spores of these three anaërobes with which in the bacterioscopic examination of filth, or of materials polluted with filth or dust, we are constantly confronted—a circumstance which might, to the uninitiated, make correct diagnosis a matter of great difficulty and lead easily to error, as I shall have opportunity to show.' A careful perusal of the remainder of the report shows that the only danger to be apprehended is that the milk reaction not being quite definite, and the organism not being pathogenic to rodents, the water might be reported as containing no B. enteritidis sporogenes; whilst it might contain the B. cadaveris sporogenes, which is, apparently, equally significant of pollution. Unless an organism obtained from a water gives all the reactions of B. enteritidis sporogenes, it must now be wrong to definitely call it by this name; but for the purposes of the water analyst it will suffice if such reactions are obtained as identify it as being either one or other of these allied organisms. The milk test in forty-eight hours practically suffices to detect the B. butyricus or B. enteritidis sporogenes, but not to differentiate them, though the absence of a definite reaction in this time does not preclude the presence of the B. cadaveris sporogenes. The incubation should be continued for seven days to ascertain whether the change indicating the presence of the latter is produced. The following Table is a slight modification of the one given by Klein of the essential differences between these three anaërobic microbes.

| I—Bacillus Enteritidis sporogenes | II—Bacillus butyricus | III—Bacillus Cadaveris sporogenes |
|---|---|---|
| 1. Cylindrical rods, on the average 2·5—3·5μ long, 0·8—1·25μ broad, stains well by Gram's method, some individuals motile. | 1. Same as I. | 1. Cylindrical and thread-like, thinner and longer than I. and II., very motile, stains by Gram's method. |
| 2. Spores oval; stain after the several methods; situated in the middle of the rods more or less, 1·6μ long, 1μ broad. | 2. Same as I. | 2. Spores oval, terminal drumsticks, stain after usual methods 1·6μ long, 1μ broad. |
| 3. On gelatine grows well, softens rapidly and slowly liquefies. | 3. Grows well on the surface of ordinary gelatine as a translucent mass of convoluted threads; does not liquefy the gelatine. | 3. Rapidly liquefying, putrid odour, numerous spores formed. |
| 4. In stab gelatine, much gas produced; spherical colonies without filamentous projections; slowly liquefying. | 4. Forms spherical colonies with numerous horizontal filamentous projections; not liquefying; forms much gas. | 4. Much gas, rapidly liquefying, and putrid odour. |
| 5. On the surface of agar, grey round flat colonies, few crenations, no spores. | 5. Grey round flat colonies, margin thin and much crenate, no spores. | 5. Thready branched colonies, with or without finely granular plate, rapidly forming spores. |
| 6. Stab in agar, little tendency for forming lateral branching, much gas, no spores. | 6. Forms characteristic bundles of threads projecting laterally from the growth in the stab, much gas, no spores. | 6. Much gas, rapidly forming spores, conspicuous masses of threads growing out of stab. |
| 7. In milk, rapid separation of acid whey and flocculi of casein, smell of butyric acid, no spores, much gas. | 7. Same as I. | 7. Milk is slowly decomposed, putrid odour, much gas, rapidly forming spores. |
| 8. Grows well on serum, slowly liquefying, some spores found. | 8. Grows well on serum, very slow softening. | 8. Rapidly liquefying, putrid odour, rapidly forming spores. |
| 9. Virulent for rodents. | 9. Not pathogenic for rodents. | 9. Not pathogenic for rodents. |

In my laboratory no attempt is made to differentiate between the Bacillus enteritidis sporogenes and the B. butyricus. With the milk test, which is the only one applied, their reactions are identical, and as the one is as likely to be derived from manurial matter as the other, differentiation is unnecessary. The B. cadaveris sporogenes is as objectionable as either of the others, and its presence is as significant of the presence of putrefying animal matter, hence it should not be found in a wholesome water. It makes its presence felt in a few days, when the flasks containing the milk are cleaned, the stench produced being of a most nauseating character. These three organisms are equally objectionable constituents of any water, and if associated with the colon bacilli, the probability of the water being polluted with decomposing animal matter, such as sewage or manure, is immensely increased. The quantitative aspect of the case will be presented later, but as the proportion of B. coli to B. enteritidis sporogenes is from 400 to 2000 to 1, it is obvious that considerable quantities of water must be examined if very minute traces of pollution are being sought for. Experience shows, however, that in a water known to be polluted, the B. enteritidis sporogenes can usually be found in about 100 c.c. to 150 c.c. of the water, if the B. coli is detected in 1 c.c.

I lay considerable stress upon the milk reaction for the bacteria of this group when applied as described in a later section. On the rare occasions in which this reaction is obtained, and colon bacilli cannot be detected, or on other occasions in which the colon bacilli are found and the B. enteritidis sporogenes or its allies cannot be discovered, other considerations, especially the examination of the source of supply, or the examination of samples from the source taken under different conditions, have generally enabled me to draw safe inferences. In the majority of instances, however, when the one organism is found the other is detected, if suitable quantities of water are used for the examination.

(*c*) *Streptococci.*—As the B. coli and the B. enteritidis sporogenes of Klein may be present in water not very recently polluted, Houston has made a further study of the subject and has come to the conclusion that recent contamination with sewage or with the washings of cultivated soil is more certainly indicated by the presence of streptococci. In his report to the Medical Officer of the Local Government Board (1899–1900), p. 458, he says:

'In studying the bacteriology of polluted soils, of crude sewage and sewage effluents, and of impure waters, I have endeavoured to find some organism, or class of micro-organism, which might be of value, if present in water; as indicating recent and objectionable pollution.

'In polluted soils, in crude sewage, in sewage effluents, and in impure waters, I have found streptococci and staphylococci to be present, often in great numbers.

'Although not discarding the class of germs known as staphylococci, I lay less stress upon them for the reason that they comprise hardy germs capable of persisting under circumstances the reverse of favourable.

'Streptococci, on the other hand, may, as a class, be thought of as germs, especially liable to discouragement by unfavourable physical conditions, and, indeed, as surviving only when the conditions are almost ideally propitious. In the present state of our knowledge, therefore, the presence of streptococci in a substance, be it soil or sewage or water, suggests recent association of certain ingredients of that substance with an animal host. I say this because streptococci are known to inhabit the alimentary tract, and for this reason, that the large numbers which I have found, and habitually found, in crude sewage (1000 or more per c.c.) lead me to conclude that the source of these germs is the recent evacuation of animals. I cannot, indeed, persuade myself that multiplication of extruded streptococci is likely to take place in raw sewage to any great extent, if at all: far more likely is it, in my belief, that they rapidly lose their vitality and die. Yet I am not claiming that all streptococci are delicate germs, for my own work is against such a view; nor am I asserting that the absence of streptococci in a water implies "purity or safety." But I contend that, in so far as streptococci, as a class, tend outside the animal body to rapidly lose their vitality and die, they are micro-organisms to be thought of as of recent animal outcome, and as not unlikely to be, moreover, pathogenic, so that, though their absence in a water may be of little moment, their presence therein is suggestive of recent pollution, and may therefore be of great importance. In brief, while not considering that the absence of streptococci implies "purity and safety" in a water supply, I am by way of urging somewhat strongly that their presence, at all events in any number, is positive evidence of a sort to go far to justify the bacteriologist in condemning a sample of water as unfit for domestic use.'

Assuming that extended observations have confirmed Doctor Houston's conclusions, the bacterioscopic examination of a water should include a search for the Bacillus coli communis, for the Bacillus enteritidis sporogenes, and also for streptococci. The discovery of the B. enteritidis spores alone may indicate contamination at a somewhat remote period ; the presence of these spores associated with the Bacillus coli communis, without streptococci, would more certainly indicate pollution, but much more recent in character; whilst the discovery of all three organisms would probably be conclusive proof of very recent contamination—that is, contamination of a very dangerous character.

Major Horrocks, however, in discussing the significance of the presence of streptococci ('Bacteriological Examination of Water,' p. 124), says : 'My experience does not support the contention that streptococci probably indicate a dangerous contamination. . . . The sewage streptococci appear to maintain their vitality in sewage for a much longer time than B. coli. Specimens of barrack sewage preserved in a laboratory cupboard for three months, and then diluted 1–100 or 1–1000 with tap water, show, when examined by the usual methods, large numbers of streptococci, but few or no Bacillus coli. Old sewage, from which B. coli has disappeared, will be unlikely to present conditions favourable to the prolonged vitality of the B. typhosus or Sp. choleræ. Consequently it appears that streptococci alone cannot be considered as necessarily indicating a dangerous contamination. It is true that when the dilutions of old sewage are kept for a few days, the streptococci rapidly disappear, so their presence in a water supply undoubtedly indicates a recent contamination, but the contamination is not necessarily dangerous, unless the streptococci are accompanied by B. coli.'

Prescott and Baker (Prescott and Winslow, 'Water Bacteriology,' p. 102 (1904)) found streptococci present in each of the fifty samples of variously polluted waters when the examination was made in a certain way, and they appear to think that the failure of others to find these organisms was probably due to a defect in the process used. They point out that they grow more slowly than the B. coli in broth, and that, if dextrose broth is used and a sufficient time allowed for growth before examining, their detection is easy. They express no opinion as to whether the presence of streptococci indicates recent contamination, but they agree that their isolation from a suspected sample of water furnishes valuable confirmatory evidence of its dangerous character.

My experience is that the presence of streptococci affords no evidence as to whether the contamination is recent or remote, and that their presence has no known significance unless they are associated with other bacteria of intestinal type. They are very rarely found in really good waters and they are not always capable of detection in undoubtedly polluted waters, therefore all that can be safely held is that if found in a water containing the colon bacilli in relative abundance their presence strongly confirms the opinion that the water is polluted with sewage or manurial matter. If the spores of the B. enteritidis sporogenes are also found, I should regard the evidence as conclusive.

(*d*) *Quantitative Considerations.*—So far nothing has been said with reference to the quantitative side of the problem. There are few, if any, waters in which the Bacillus coli cannot be found if a sufficient quantity of the water be taken for examination, and the other organisms above referred to may on occasions be found in pure waters, if samples are sufficiently often examined and large quantities used for the purpose. As the detection of sewage or manurial contamination by bacteriological methods must depend upon the discovery of the bacteria characteristic of excremental matter, a very important point remains for discussion, viz. the amount of water which should be used for the examination. Chemical analysis cannot be depended upon to detect pollution with 0·1 per cent. of sewage, or with 1 per cent. of most sewage effluents, which sewage effluents might practically contain all the organisms of the original sewage. Bacterioscopic analysis may be depended upon to detect a much smaller quantity of polluting matter. Unfortunately the number of the selected organisms found in sewage varies enormously, and the proportion of each to the others varies in every sample. In relative abundance they occur in the following order: Bacillus coli communis, streptococci and spores of the Bacillus enteritidis sporogenes of Klein. Houston and Klein find the variations are within the following limits:

| | | |
|---|---|---|
| Bacillus coli communis . . . . | 100,000 to 800,000 | per c.c. |
| Streptococci . . . . . . | 1,000 to 10,000 (?) | „ |
| Spores of B. enteritidis sporogenes . | 100 to 2,000 | „ |

Assuming that efforts are limited to the detection of pollution corresponding to one-millionth part of sewage containing the minimum number of these organisms, it is obvious 10 c.c. of the water would be required to give indication of the presence of the Bacillus coli, 1000 c.c., or one litre, to afford evidence of streptococci, and ten litres for the detection of the spores of the B. enteritidis sporogenes.

On the other hand, assuming the polluting matter to contain the maximum number of the above organisms, 1 to 2 c.c. would suffice for the detection of the B. coli communis, 100 c.c. for streptococci, and 500 c.c. for the spores of the B. enteritidis sporogenes.

I am convinced that standards cannot be adopted applicable to all waters, but there is very little doubt that a water which gives no indications of the presence of bacteria of the colon group in 20 c.c., of streptococci in 50 c.c., and of the spores of B. enteritidis sporogenes in 500 c.c., is at the time of examination so free from sewage pollution that it may be certified as safe for all domestic purposes, provided its source is known to be satisfactory.

This standard is attained by waters from all properly protected springs and most properly constructed deep wells. Upland and moorland surface waters, collected in reservoirs, may be regarded as satisfactory if they afford no evidence of the presence of the Bacillus coli communis in 10 c.c., and especially if the B. enteritidis sporogenes cannot be detected in 250 c.c. Water which has been stored in a reservoir would not be expected to contain any streptococci, and if their presence was discovered I should lay no stress upon this fact unless colon bacilli were also present in relative abundance.

Shallow wellwaters present the gravest difficulty. If they were expected to satisfy the standard provisionally adopted for moorland waters, a great many shallow wells yielding safe waters would have to be condemned. In these cases more stress should be laid upon the situation and construction of the well, and the way in which the water enters, than upon the bacterioscopic results. I have found, however, that nearly all wells which are properly constructed and which are at a little distance from highly manured ground, and the water from which does not become turbid after rain, yield waters affording no evidence of the presence of colon bacilli in 10 c.c., or of the spores of the B. enteritidis sporogenes in 250 c.c., but it must be remembered that many wells sunk in a polluted subsoil or in positions rendering them liable to pollution give no signs of pollution when examined bacteriologically.

Some interesting results obtained by Mr. Strachan and myself were published in *Public Health* (June 1905) as the result of the examination of mixtures of filtered water and sewage. In the first experiment recorded, 1 c.c. of crude sewage from the main outfall sewer at Watford was mixed with 100,000 parts of London tap-water, and analyses made of the pure and polluted tap-water and of the sewage.

The sewage contained over 900,000 bacteria, forming visible growths on gelatine in three days and 1,800,000 visible on the fourth day. It contained the B. coli in $\frac{1}{100000}$ of a c.c. and the B. enteritidis sporogenes in $\frac{1}{1000}$ of a c.c.

The polluted water was kept in a cool place and examined at intervals with the following results :

TAP-WATER POLLUTED WITH SEWAGE, 1 PART SEWAGE IN 100,000 PARTS WATER

| Number of days after pollution | Number of Organisms per c.c. counted after | | Number of c.c. in which B. C. C. found | Number of c.c. in which B. E. S. found |
|---|---|---|---|---|
| | 3 days | 4 days | | |
| 0 | 13 | 27 | 1 | 125 |
| 2 | 163 | 249 | 10 | ? (experiment (spoiled) |
| 4 | 476 | liquid | 5 | 375 |
| 6 | liquid | ,, | 5 | not in 500 |
| 9 | 2022 | ,, | 20 | ,, 500 |
| 14 | liquid | ,, | not in 36 | ,, 500 |

In this experiment the B. coli could be detected in 20 c.c. or less for nine days, but on the sixth day the B. enteritidis sporogenes could not be detected in 500 c.c. In nine days the B. coli must have been reduced to, at least, $\frac{1}{20}$ of their original number, and the B. enteritidis sporogenes to less than $\frac{1}{5}$ in six days.

The bacteria growing on gelatine had continuously increased up to the ninth day, and showed no signs of decreasing on the fourteenth day.

A second experiment was made in exactly the same way and with the same dilution, but using a sewage which chemically was stronger. It contained over ten millions of bacteria per c.c., but apparently about the same number of B. coli and of B. enteritidis sporogenes as the sewage first used.

The results obtained were as under:

TAP-WATER POLLUTED WITH SEWAGE, 1 PART SEWAGE IN 100,000 PARTS WATER

| Number of days after pollution | No. of Organisms per c.c. counted after | | | Number of c.c. in which B. C. C found | Number of c.c. in which B. E. S. found |
|---|---|---|---|---|---|
| | 2 days | 3 days | 4 days | | |
| 0 | 111 | liquid | liquid | 1 | 125 |
| 3 | 156 | 367 | ,, | 1 | 375 |
| 6 | 239 | 366 | ,, | 5 | not in 500 |
| 9 | 341 | 707 | 2345 | 10 | ,, 500 |
| 12 | 403 | 1775 | 5080 | 36 | ,, 500 |
| 15 | 574 | 1920 | liquid | not in 36 | ,, 500 |

In this case also the bacteria continuously increased up to the 15th day, when the experiment ended, but the B. coli was absent in 20 c.c. on the 12th day and in 36 c.c. on the 15th day. The B. enteritidis sporogenes could not be detected in 500 c.c. on the sixth day.

In the next experiment the tap-water was polluted by adding 1 c.c. of crude sewage to a litre, and one sample was exposed to diffused daylight and the other kept in the dark.

The results were as under:

TAP-WATER POLLUTED WITH SEWAGE, 1 PART SEWAGE IN 1000 PARTS TAP-WATER

POLLUTED WATER KEPT IN THE DARK

| Number of days after pollution | Number of Organisms per c.c. counted after | | | Number of c.c. in which B. C. C. found | Number of c.c. in which B. E. S. found |
|---|---|---|---|---|---|
| | 2 days | 3 days | 4 days | | |
| 0 | 15,700 | liquid | liquid | 1 | 150 |
| 3 | 34,900 | ,, | ,, | 1 | 150 |
| 6 | 11,100 | ,, | ,, | 1 | 150 |
| 9 | 2,050 | 3500 | 5100 | 1 | 150 |
| 12 | 985 | 1565 | 1980 | 5 | 150 |
| 16 | 555 | 1220 | 1670 | 5 | 150 |
| 20 | 830 | 1560 | 3550 | 10 | 150 |
| 24 | 700 | 1820 | 7600 | 36 | (experiment accidentally spoiled) |
| 26 | | not put on | | not in 36 | 350 |
| 35 | | ,, | | ,, | 350 |

### TAP-WATER POLLUTED WITH SEWAGE, 1 PART SEWAGE IN 1000 PARTS TAP-WATER

#### POLLUTED WATER EXPOSED TO THE ACTION OF LIGHT

| Number of days after pollution | Number of Organisms per c.c. counted after | | | Number of c.c. in which B. C. C. found | Number of c.c. in which B. E. S. found |
|---|---|---|---|---|---|
| | 2 days | 3 days | 4 days | | |
| 0 | 15,700 | liquid | liquid | 1 | 150 |
| 2 | 23,600 | ,, | ,, | 1 | 150 |
| 4 | 19,700 | ,, | ,, | 1 | 150 |
| 6 | liquid | ,, | ,, | 1 | 150 |
| 8 | 3,700 | 7000 | 8850 | 1 | 150 |
| 10 | 1,950 | 4650 | 8400 | 5 | 150 |
| 12 | 480 | 1025 | 1580 | 20 | 150 |
| 15 | 905 | 1810 | liquid | not in 36 | 150 |
| 20 | 2,095 | 2960 | ,, | ,, | 150 |
| 24 | 1,990 | 2140 | ,, | ,, | 150 |
| 26 | | not put on | | | 150 |

The crude sewage kept in the dark contained the B. coli in 1 c.c. after twenty-seven days, that is, until the end of the series of experiments. Up to the ninth day the typical *enteritidis* change could be obtained with 1 c.c., on the 16th day it could not be obtained with less than 4 c.c., up to the 24th day it was found in 10 c.c. but not in 5 c.c., and on the 27th day it could not be obtained with less than 10 c.c. With the sewage exposed to light the results were practically identical, but on the 27th day the *enteritidis* change could be effected with 8 c.c.

Apparently the B. coli disappears from a water more rapidly if it is exposed to light than if kept in the dark, whereas the opposite seems to be the case with the B. enteritidis sporogenes. The rapidity with which the B. coli disappears depends upon the extent of the pollution. Even with 1 part of sewage in 100,000 of water it is either not found at all, or only in relatively large proportions of water at the end of fourteen days, and the B. enteritidis sporogenes may not be found in 500 c.c. of water after six days, but in Experiments III., A and B, the spores were present at the end of thirty-five days. The greater the extent of the original pollution, the longer the period throughout which both can be detected. In water recently contaminated with one-millionth part of sewage, it would appear to be useless to expect to find the B. enteritidis sporogenes in less than 1 litre of water, hence unless gross contamination only is to be detected the use of smaller quantities would appear to give results of no value.

Notwithstanding theory, practical experience indicates that the test for the presence of the B. enteritidis sporogenes in quantities of water varying from 10 c.c. to 1 litre is useful, not so much perhaps as an indication of sewage pollution as of the presence of surface water derived from land under cultivation.

I was seriously impressed with this when investigating the source of a water supply in which the spores of this bacillus had made their appearance. I found that manurial matter from a farmyard soaked away in an adjoining field, and that after a heavy rainfall surface water from this field would inevitably find its way into the spring water from which the supply was derived. I collected a little of the earth which had been carried down to a point near the spring, and upon examination I found that it contained no colon bacilli, but that the spores of B. enteritidis sporogenes were present in great abundance. Again and again the presence of this bacillus has indicated undesirable surface relationship, and further investigation has led to the verification of the surmise. For this reason I continue to employ the test in the routine examination of all waters.

The results obtained upon examining waters for the various B. coli groups and for the spores of B. enteritidis sporogenes may be grouped as under :

1. Waters 100 c.c. of which contain no bacteria capable of fermenting bile-salt glucose broth, and which contain no spores of the B. enteritidis sporogenes or its allies in 250 c.c. These are of the highest degree of purity, and afford no evidence of pollution with sewage or manurial matter, or with surface water.

2. Waters 100 c.c. of which contain no bacteria capable of fermenting bile-salt glucose broth, but which contain the spores of B. enteritidis sporogenes or its allies. It will generally be

found that a little surface water is gaining access to the water and that otherwise it would be of excellent quality.

3. Waters 100 c.c. of which contain bacteria capable of fermenting bile-salt glucose broth, but not lactose broth, and which are free from the spores of B. enteritidis sporogenes and its allies. Waters of this character are very common. They are not of so high a degree of bacterial purity as those of Group 1, but they afford no evidence of contamination with sewage, manure, or surface water.

4. Waters 100 c.c. of which contain bacteria capable of fermenting bile-salt glucose broth, but not lactose broth, and giving the milk reaction for B. enteritidis sporogenes and its allies. Such waters will almost invariably prove to be more or less affected by admixture with surface water or imperfectly filtered subsoil water.

5. Waters giving with 100 c.c. or less the presumptive and confirmatory reactions for the presence of colon bacilli, but not containing the true B. coli (flaginac, saginac, and aginac) and not giving the B. enteritidis sporogenes reaction with the milk test. These waters give indications of surface relationship or of being derived from subsoil, which has been affected by manurial matter. Whilst not exhibiting signs of dangerous pollution, some knowledge of the source would be required before giving a definite opinion. Repeated analyses should also be made, and especially of samples collected after heavy rainfalls.

6. Waters as group 5, but containing also the B. enteritidis sporogenes in 250 c.c., or under. These waters give more decisive indication of the presence of impurities derived from an objectionable source, and inquiries and inspections should be made before giving any definite opinion.

7. Waters containing bacteria of the true colon type, but no spores of B. enteritidis sporogenes in 250 c.c.

Here the questions of 'relative abundance' and the source of the water have to be taken into consideration. The majority of waters submitted to examination come into this class, and give rise to endless disputes as to the interpretation of the results.

The water may contain colon bacilli in 1 c.c. and yet be derived from a source beyond the risk of pollution, or it may only contain a single colon bacillus in 100 c.c., and yet this come from a dangerous source. If the B. coli is not found in 20 c.c. and streptococci cannot be found in 50 c.c., or B. enteritidis sporogenes in 500 c.c., the pollution at the time the sample was taken could scarcely have been of a dangerous character, but further examinations alone can tell whether more serious contamination ever occurs. Moorland and upland waters may not reach even this standard, and yet be perfectly wholesome, if the source upon examination is found free from the risk of contamination by human beings.

8. Waters containing both B. coli and the spores of B. enteritidis sporogenes. Such waters must be regarded as contaminated with sewage or manurial matter, but whether dangerous or not can only be ascertained (if at all) by an examination of the source. I have known the presence of a large number of gulls on a reservoir cause pollution of this character. I could not say that the water was unwholesome, but it enabled me to press the necessity for careful filtration.

It is perfectly obvious that a chemical or bacteriological examination of a sample of water can only justify an opinion upon that particular sample, and not upon the source from which it was obtained. Yet a large number of people who send odd samples of water for examination conclude that if the report is satisfactory, the source is also satisfactory. It is quite true that if the water is found to be polluted, the source is unsatisfactory (assuming that the sample was properly taken), but it does not follow that if the sample is of good quality the source is a safe one from which to derive water. The source which yielded the impure sample may be inherently unsatisfactory and incapable of being made satisfactory, or, on the other hand, it may admit of being adequately protected, possibly with very little trouble or expense.

The next Table (*vide* p. 237) gives the results of the examination of a few samples of water, with remarks upon them, which illustrate the application of the above observation.

## RESULTS OF THE BACTERIOLOGICAL EXAMINATION OF VARIOUS SAMPLES OF WATER

| | Group | Source of Water | No. of Colonies, per c.c. | Growth in bile-salt glucose Broth | | Smallest quantity producing growth | Growth on Lactose bile-salt Agar | Lactose Broth | | Motility | Gram's Stain | Fluorescence | Litmus Milk | | Liquefaction of Gelatine | Indol Formation | B. Ent. Sporogenes, or near ally | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Acid | Gas | | | Acid | Gas | | | | Acid | Clot | | | 150 c.c. | 350 c.c. |
| a | I | Spring in Plantation | 260 | − | − | −100 c.c. | | | | | | | | | | | − | − |
| b | ,, | Bored well in chalk | 18 | + | − | −100 c.c. | | − | − | | | | | | | | − | − |
| c | II | Bored well 375 feet deep . . . | | − | − | −100 c.c. | | | | | | | | | | | − | + |
| d | III | Gravel beds. Public supply . . | | + | + | 1 c.c. | Few white colonies . | + | − | | | | | | | | − | − |
| e | ,, | River and deep wells supply . . | 18 | + | + | 1 c.c. | ,, ,, | + | − | | | | | | | | − | − |
| f | IV | Well-water . . | | + | + | 10 c.c. | Many white colonies, 1 red . . . | + | − | + | − | − | + | + | − | − | − | + |
| | | | | | | | | + | − | + | | + | − | D | − | − | | |
| g | V | Spring-water . . | 10,000 | + | + | 1 c.c. | Red colonies. No haze | + | + | − | − | − | + | + | − | − | − | − |
| h | ,, | Moorland supply . | 20,000 | + | + | 1 c.c. | Red and white colonies . . | + | + | + | | − | + | − | − | + | − | − |
| | | | | | | | | + | + | + | | − | + | − | − | + | | |
| | | | | | | | | + | + | + | | − | + | − | − | + | | |
| | | | | | | | | + | − | + | | | | | | | | |
| i | VI | River-water supply | Innumerable | + | + | 1 c.c. | Red with haze . . . | + | + | + | − | − | + | − | − | + | − | + |
| j | VII | Deep well in oolite formation . . | 166 | + | + | 10 c.c. | Red colonies + haze . | + | + | + | − | − | + | + | − | + | − | − |
| k | ,, | River-water supply | 124 | + | + | 10 c.c. | ,, ,, | + | + | + | − | + | + | + | − | + | − | − |
| | | | | | | | | + | + | + | − | − | + | + | − | + | | |
| l | ,, | ,, ,, | 260 | + | + | 1 c.c. | ,, ,, | + | + | + | − | + | + | + | − | + | | − |
| m | ,, | Bagshot sand supply | | + | + | 10 c.c. | ,, ,, | + | + | + | − | − | + | + | − | + | | − |
| n | ,, | Bored well nearly 1000 feet deep . | | + | + | 1 c.c. | ,, ,, | + | + | + | | + | + | + | − | + | | − |
| o | VIII | Shallow well . . | | + | + | 1 c.c. | ,, ,, | + | + | + | − | − | + | − | − | − | + | + |
| | | | | | | | | + | + | + | − | − | + | − | − | + | | |
| | | | | | | | | + | + | + | − | − | + | + | − | + | | |

NOTE.—Where the results of the examination of one colony only are recorded, all the colonies examined were identical in character.

*Group* 1.—(*a*) This spring arose in a plantation and it was proposed to utilise it for supplying drinking water to an Institution. Excellent as were the bacteriological results, I would not sanction the use of the spring until I had examined the ground around. The result was the discovery of a cesspool, the overflow from which could have reached the spring and which had to be removed before the spring could be utilised.

(*b*) From a deep well in the chalk near a tidal river, the water in which was seriously polluted with sewage. The water-level was affected by the tide, and after the well had been in use some time the salinity began to increase and the well had ultimately to be abandoned.

*Group* 2.—(*c*) From a boring made through London clay into the chalk beneath. The sample was taken from the bore-pipe, and I noticed that this had been plugged with a sod. Hence the B. enteritidis sporogenes found in the sample.

*Group* 3.—(*d*) From a series of Abyssinian tube-wells driven in a large patch of gravel about 100 yards from a cemetery. The consumers were afraid of contamination arising from the graveyard. From an examination of the ground, I concluded that such pollution was practically impossible. Although many samples have since been examined, the water has never shown signs of contamination.

(*e*) A public supply chiefly derived from deep wells, but often supplemented by filtered river-water. At various times the B. coli was found in this water, and analysts had reported it as being polluted. Knowing the waterworks and the care taken in filtering the river-water, I have always regarded the supply as being 'safe.'

*Group* 4.—(*f*) A shallow well-water. An examination of the well showed that a little surface water gained access. There was no possibility of pollution by sewage or manure.

*Group* 5.—(*g*) A spring water from a dangerous source. A public urinal discharged into a ditch about 200 yards above the point at which the spring arose. The excessive number of bacteria as well as their nature suggested the necessity for an examination.

(*h*) A public supply from the Welsh moorlands. No sewage contamination possible. A water of this kind should be filtered before being delivered to the consumers.

*Group* 6.—(*i*) A water of exactly the same character as (*h*), derived from a Welsh stream and supplying a fairly large population. Liable to sewage pollution and to contamination from agricultural land.

*Group* 7.—(*j*) A deep well supply which was believed to be beyond suspicion of pollution. Subsequently the B. enteritidis sporogenes was found in it, and it was ultimately discovered that there was a connection between the well and a distant 'swallow-hole,' into which polluted water flowed from a stream whenever there was a heavy rain.

(*k*) and (*l*) Typical of results obtained with filtered river-waters. Both were Thames-derived waters, taken from points nearest the filter beds. Neither could be considered satisfactory, but (*l*) was an exceptionally bad sample. One filter bed was found to be passing a very impure water.

(*m*) A small public supply derived from a well in the Bagshot sands. A cesspool was found, which overflowed upon the field in which the well was sunk and within about forty yards of it. The position was so dangerous that a fresh source of supply had to be provided.

(*n*) This is a water which has previously been referred to. Although pollution by sewage or manure is impossible, there are many deep wells in Essex yielding water which, on occasions, contain colon bacteria in as little as 1 c.c.

*Group* 8.—(*o*) A shallow well-water suspected to be the cause of a limited outbreak of enteric fever. Note that only one of the red colonies examined proved to be a true coli (aginac). The surroundings of the well were unsatisfactory, and pollution after heavy rain almost certain.

The qualitative aspect of the case really depends upon the number of the particular bacteria found in fæces selected for detection. In stools from patients suspected to be suffering from typhoid fever, I have found 1000 million B. coli per gramme, and upon the neutral-red agar plates the proportion of streptococci to bacteria of the coli group was 1 to 30 or 40, which would give some twenty-five million streptococci per gramme. With two-millionth of a gramme the milk reaction for B. enteritidis sporogenes was obtained. If one part of fæcal matter of this kind were added to 10,000,000,000 parts of water, the B. coli would be found in 10 c.c.; but to detect the streptococci about half a litre would be required, and no less than five litres would have to be used to detect the B. enteritidis sporogenes. These large quantities of water cannot be conveniently used, nor, if used, would there be any certainty of detecting the streptococcus or the spores of B. enteritidis sporogenes. In a dilution of 1,000,000,000, the presence of B. coli in 1 c.c. would raise grave suspicion of pollution, and a careful examination of larger quantities of the water might be expected to reveal the presence of the two other organisms, and so conclusively prove the contamination.

In reporting to the Local Government Board on the 'Bacteriological examination of the normal stools of healthy persons,'[1] Dr. Houston gives a brief approximate statement of his average results. Per gramme of fæces he found :

| | |
|---|---|
| Total number of bacteria on gelatine at 20° C. and agar at 37° C. | 100, not 1000 million |
| Bacillus coli | ,, ,, ,, |
| Streptococci | At least 100,000 (probably an under-estimate) |
| B. enteritidis sporogenes test | 1, not 10 million |

It is noteworthy that in fæces practically the whole of the bacteria will grow on agar-plates, forming colonies in twenty-four hours, and that the majority of these colonies consist of bacteria of the coli groups.

There is a tendency amongst chemists and bacteriologists who examine waters to report unfavourably upon any sample which contains the colon bacilli in 100 c.c., and frequently the action causes a great deal of unnecessary alarm. This is said to be Houston's standard, totally regardless of the fact that he has always asserted that this standard is only tentative and is to be 'controlled by knowledge of local conditions.' No doubt, also, Dr. Houston is endeavouring to get the London water supply up to this standard of purity, but because it frequently fails to reach this high standard he does not alarm the Metropolis every time he discovers the B. coli in 10 c.c. or 1 c.c. of the water supplied. If he did, we should live in a continuous state of alarm.

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[1] *Report of the Medical Officer to the L.G.B.*, 1902–3, p. 538.

The following averages for the year 1910 and 1911 are taken from Dr. Houston's report to the Metropolitan Water Board for December 1911. It will be noted that on many occasions the Bacillus coli is found in 10 c.c. or less of the filtered waters, and on rare occasions in 1 c.c. or even in less.

| Source | Percentage of Samples of well-waters (unfiltered) and of filtered river-waters, containing the typical B. coli in the undermentioned quantities of water | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Not present in 100 c.c. | Present in 100 c.c. | In 10 c.c. | In 1 c.c. | In ·01 c.c. | In ·001 c.c. |
| *Well-waters—* | | | | | | | |
| Kent district . . | 1910 | 97·5 | 2·4 | — | — | — | — |
| | 1911 | 96·6 | 2·5 | 0·8 | — | — | — |
| Eastern and New River district . . . | 1910 | 93·7 | 4·2 | 1·0 | — | — | — |
| | 1911 | 92·1 | 7·1 | 0·8 | — | — | — |
| *Filtered waters—* | | | | | | | |
| Rye Common . . | 1910 | 65·6 | 25·3 | 8·4 | 0·6 | — | — |
| | 1911 | 92·2 | 4·9 | 2·9 | — | — | — |
| New River . . | 1910 | 81·4 | 14·4 | 3·7 | 0·3 | 0·07 | — |
| | 1911 | 83·4 | 13·4 | 2·6 | 0·5 | — | — |
| East London (Lea) . | 1910 | 86·0 | 10·5 | 2·9 | 0·5 | — | — |
| | 1911 | 84·6 | 11·6 | 2·8 | 0·7 | 0·2 | — |
| Kempton Park . . | 1910 | 92·3 | 7·2 | 0·4 | — | — | — |
| | 1911 | 83·2 | 12·2 | 4·5 | — | — | — |
| East London (Thames) | 1910 | 45·7 | 42·8 | 11·4 | — | — | — |
| | 1911 | 54·4 | 32·0 | 9·7 | 2·9 | 0·9 | — |
| Chelsea . . . . | 1910 | 86·8 | 12·2 | 1·0 | — | — | — |
| | 1911 | 83·4 | 13·1 | 2·5 | 0·6 | 0·3 | — |
| Grand Junction . . | 1910 | 79·7 | 15·6 | 3·9 | 0·5 | 0·2 | — |
| | 1911 | 81·6 | 13·4 | 4·5 | 0·4 | — | — |
| West Middlesex . . | 1910 | 76·8 | 18·9 | 4·0 | 0·2 | — | — |
| | 1911 | 65·9 | 22·7 | 9·0 | 1·8 | 0·4 | 0·1 |
| Southwark and Vauxhall | 1910 | 79·9 | 16·3 | 3·0 | 0·5 | 0·2 | — |
| | 1911 | 64·9 | 22·3 | 10·8 | 1·6 | 0·3 | — |
| Lambeth . . . | 1910 | 79·1 | 16·3 | 3·0 | 0·5 | 0·2 | — |
| | 1911 | 78·8 | 17·8 | 3·2 | 0·2 | — | — |
| All Thames-derived waters | 1910 | 80·8 | 15·6 | 3·1 | 0·4 | 0·08 | — |
| | 1911 | 73·8 | 18·2 | 6·6 | 1·0 | ·02 | ·02 |

Dr. Houston appears to have ceased to make examinations for streptococci as they are not referred to in recent reports. This does not occasion any surprise as the examinations afforded no information of value. The B. enteritidis sporogenes test appears only to be applied to the raw and stored waters, and not more than 10 c.c. of water is used. The results, however, showed the marked improvement effected by storage. His averages for 1910 and 1911 were as under:

BACILLUS ENTERITIDIS SPOROGENES IN RIVER AND STORED WATERS

| | | Test negatives with 10 c.c. | Positive with 10 c.c. | Positive with 1 c.c. | Positive with ·01 c.c. |
|---|---|---|---|---|---|
| *Raw waters*— | | | | | |
| Thames water . . | 1910 | 51·9 | 42·3 | 5·8 | — |
| | 1911 | 65·4 | 32·7 | 1·9 | — |
| Lea water . . . | 1910 | 55·8 | 36·5 | 7·7 | — |
| | 1911 | 67·3 | 30·8 | 0·0 | 1·9 |
| River water . . . | 1910 | 94·2 | 5·8 | — | — |
| | 1911 | 88·2 | 11·5 | — | — |
| *Stored waters*— | | | | | |
| Staines . . . . | 1910 | 96·1 | 3·8 | — | — |
| | 1911 | 94·2 | 5·7 | — | — |
| Chelsea . . . | 1910 | 82·7 | 17·3 | — | — |
| | 1911 | 94·2 | 5·7 | — | — |
| Lambeth . . . | 1910 | 94·2 | 5·8 | — | — |
| | 1911 | 92·7 | 7·7 | — | — |
| Lea (East London) . | 1910 | 100·0 | — | — | — |
| | 1911 | 100·0 | — | — | — |

To clear up all doubt as to Dr. Houston's views, I asked him to favour me with replies to two questions. This he has kindly done, and though his replies are somewhat lengthy, they are of sufficient importance to be given *in extenso.*

*Question* 1.—What bacteriological proof would you consider conclusive as to the pollution of a water with sewage or manurial matter?

An *absolute* answer to this question is hardly possible. There are probably no microbes which are found only in sewage, or in substances known to be polluted with sewage and never found in waters which are free (or apparently free) from undesirable pollution.

Again, the answer must needs be *relative*, for the water is either seemingly safe or its condition somewhat speculative, according to whether it approximates towards one or other of the following two extremes. Some waters are generally so pure that no B. coli (lactose + indol +) can be isolated from 100, 1000, nay, even from 10,000 c.c. of water. Most sewages, on the other hand, contain 100,000 B. coli[1] per c.c. If a water contained 1000 or more B. coli per c.c., the presumption that it was sewage-polluted would be exceedingly strong. If, however, it contained B. coli in 100 but not in 10 c.c., no such dogmatic opinion could be expressed with assurance. Not even the boldest topographist dares to translate his vague expressions of opinion into precise terms of degrees of sewage pollution; on the contrary, he shelters himself behind such varying phrases as polluted, seriously polluted, dangerously polluted, and the like, which, having no definite value, can never be seriously challenged. The bacteriologist, on the other hand, can with assurance assert of any particular water that it is relatively 10, 100, 1000, 10,000, 100,000, or one million times less impure *qua* B. coli than sewage (or its bacteriological equivalent). To say at what point the evidence of sewage pollution is conclusive, or altogether decisive, depends on a balance of considerations, including the varying circumstances that similar bacteriological results do not *necessarily* call for the same expression of opinion.

The fact is that the bacteriologist starts provisionally with certain observed data, but if he is wise he will suspend his final judgment until he has taken stock of all the circumstances, which may bear on the particular case in point. For example, a *river-water* known to contain initially 100 B. coli per 1 c.c. may be brought by long storage into the condition of yielding positive results, only with 100 c.c., but not with 10 c.c. of water. This water in the trained judgment of an expert has an inner history which speaks almost conclusively, though only inferentially, of nearly perfect safety. On the other hand, *a well-water* definitely known to be liable to *fresh* sewage pollution and yielding similar bacteriological results (+ 100 − 10 c.c.) cannot be regarded as quite in the same category.

Yet again, a water derived from an *upland gathering ground*, remote from the possibilities of human excremental pollution, might contain B. coli in 100 c.c. (and even in less), and yet be perfectly safe for drinking purposes.

In these varying cases nearly everything depends on the personal experience of the expert.

*Deep wells* rarely contain B. coli in 100 c.c. (iamors).[2]

Shallow wells yield the most variable results, sometimes very good and not infrequently very bad. In either case, local inspection is most desirable before venturing upon any definite conclusions. Not a few *upland or moorland supplies* are so pure that even without filtration they do not contain B. coli in 100 c.c. (iamors). *River-water supplies* are almost expected to be polluted and usually require some form of artificial purification or storage before they can, with any confidence, be supplied to consumers.

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[1] To avoid repetition, B. coli, unless otherwise stated, implies here a microbe, forming gas in lactose cultures and indol in peptone water cultures.

[2] Iamors = in a majority of representative samples, preferably not less than ten.

We know now that it is by no means impracticable so to purify these waters that the final product contains no B. coli in 100 c.c. (iamors).

For example, the Metropolitan Water Supply during the year 1911 yielded the following average results :

PERCENTAGE NUMBER OF SAMPLES CONTAINING B. COLI IN 100 C.C. (OR LESS) OF WATER

| Thames-derived | Lea-derived | New River-derived |
|---|---|---|
| 26·2 | 15·4 | 16·6 |

The prolonged experience of the writer leads him to doubt whether, in any circumstances, the standard of '*a negative B. coli result with* 100 *c.c. of water* (*iamors*)' is so severe as to be unattainable; but he distinctly advocates that a final judgment as regards a water should be based on a *summation of verdicts* (topographical, geological, epidemiological, physical, chemical, and bacteriological).

Although the chance isolation of B. coli from 100 c.c. of water is not necessarily a convincing proof of sewage pollution, yet as we descend the decimal scale of dilutions (10 c.c., 1 c.c., 0·1 c.c., 0·01 c.c., &c.) the evidence becomes proportionately (if not more than proportionally) stronger. It is hardly possible, however, to assign a point beyond which suspicion assumes the garb of certainty.

It is far better to look with *preliminary* suspicion on a water evidencing B. coli in 100 c.c. (iamors), and as regards waters yielding positive results with 10 c.c., 1 c.c. (or less), to consider that they are, *on the basis of the test*, ten, a hundred or more times, less satisfactory than the tentative standard here suggested.

The position taken up by the writer in 1902 is not remote from that now suggested in this note.[1]

'So far as my experience of the bacteriological examination of soils, soil "washings," sewage, sewage effluents, fæces, and water is concerned, I am certainly of opinion that a fixed standard is not yet available. But a *tentative* standard, or rather a series of standards, for working purposes *clearly meant to be governed or controlled by knowledge of local conditions and other circumstances* may prove of great

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[1] 'Bacteriological examination of normal stools of healthy persons,' App. B, No. 5, p. 559 *et seq.*, *Report of the Medical Officer, Local Government Board*, 1902–3.

*comparative* value. In this strictly limited sense, a safe indication of the probable truth may be expressed as follows :

| Class | QUANTITATIVE.—(Whenever possible plurality of samples should be examined. When this is impossible great caution should be exercised in drawing inferences from the examination of chance samples.) |
|---|---|
| 1st | – 100 c.c.—A water showing no evidence (bacteriologically) of recent objectionable contamination, and therefore, in the absence of conditions of an actually or potentially dangerous kind, seemingly ‘safe’ for domestic use. |
| 2nd | + 100 c.c. – 10 c.c.—A water showing appreciable evidence (bacteriologically) of presumably objectionable contamination, and therefore, not absolutely free from the suggestion of being potentially, if to an almost negligible extent, dangerous to health.<br>This class may be subdivided as follows :<br>+ 1000 – 90<br>+ 90 – 80<br>+ 80 – 70<br>+ 70 – 60<br>+ 60 – 50<br>+ 50 – 40<br>+ 40 – 30<br>+ 30 – 20<br>+ 20 – 10<br>But how far this is practicable, and if practicable, how far present knowledge permits drawing conclusions on such a refined basis, is another question. |
| 3rd | + 10 c.c. – 1 c.c.—A water showing definite evidence (bacteriologically) of contamination presumably objectionable in character, and therefore to be regarded with some suspicion.<br>This class may be subdivided as follows :<br>+ 10 – 9<br>+ 9 – 8<br>+ 8 – 7<br>+ 7 – 6<br>+ 6 – 5<br>+ 5 – 4<br>+ 4 – 3<br>+ 3 – 2<br>+ 2 – 1<br>See note above. |
| 4th | + 1 c.c. – ·1 c.c.—A water showing such obvious indications (bacteriologically) of pollution presumably objectionable in character as hardly to fall within the category of waters, reasonably safe for potable purposes, *in the absence of contra-indications of a convincing kind.* |

| Class | QUANTITATIVE.—(Whenever possible plurality of samples should be examined. When this is impossible great caution should be exercised in drawing inferences from the examination of chance samples.) |
|---|---|
| | This class may be subdivided as follows :<br>+ 1 c.c. — ·9<br>+ ·9 — ·8<br>+ ·8 — ·7<br>+ ·7 — ·6<br>+ ·6 — ·5<br>+ ·5 — ·4<br>+ ·4 — ·3<br>+ ·3 — ·2<br>+ ·2 — ·1<br>See note above. |
| 5th | + ·1 c.c. — ·01 c.c.—A water showing such clear evidence (bacteriologically) of presumably objectionable contamination as to be quite unfit for domestic use, *on the basis of this test.* |
| | This class may be subdivided as follows :<br>+ ·1 c.c. — ·09<br>+ ·09 — ·08<br>+ ·08 — ·07<br>+ ·07 — ·06<br>+ ·06 — ·05<br>+ ·05 — ·04<br>+ ·04 — ·03<br>+ ·03 — ·02<br>+ ·02 — ·01<br>See note above. |
| 6th | + ·01 c.c. — ·001 c.c.—A good sewage effluent. Further comment is superfluous. |

'As regards quantitative testing, I hesitate to suggest a fixed standard, but desire to point out that a moderate view to take, generally speaking, would be that a water in the fifth class should certainly be rejected; in the fourth class probably, if not certainly, still be rejected; in the third class viewed with some suspicion; and in the second class considered not wholly free from evidence (bacteriological) of pollution, presumably of objectionable sort.

'Each case, however, must needs be judged *on its own merits, and in relation to the local conditions.*'

Up to this point 'lactose + indol +' B. coli have alone been considered, because in the writer's opinion the quantitative estimation of such microbes should form the preliminary basis for judging degrees of probable excremental contamination. But the application of additional fermentative (e.g. saccharose, raffinose, dulcit, salicin, adonite, glycerine, &c.) and other tests so as to classify the 'lactose + indol' microbes into a number of varieties, or sub-varieties, is in no way discouraged. At present it may be difficult or impossible to assign to these varieties any very definite place in a scale representing degrees of undesirable pollution, but the gradual accumulation of these observed facts should, in course of time, yield results of definite value.

The results yielded by the gelatine, agar, and bile-salt agar tests are of great value if judiciously interpreted. In fresh fæces these tests may yield approximately similar results because nearly all the micro-organisms in fæces are excremental bacteria ; but in waters the first test yields, usually, considerably higher results than the second, and the second than the third.

A consideration of the ratios may be of elucidatory importance to the expert, but the writer hesitates to deal with so controversial a subject in this brief note. Conclusions based solely, or even largely, on ratios are certainly to be deprecated.

As regards supplemental or corroborative tests, generally applied simultaneously, besides the gelatine (20° C.), agar (37° C.), and bile-salt agar (37° C.) tests, there are those dealing with the number of spores of B. enteritidis sporogenes, and others with the number of streptococci.

With sewages the so-called B. enteritidis sporogenes change is usually manifested with 1/100th to 1/1000th of a cubic centimetre.

This test when positive is a better corroborative measure of impurity than its converse is a proof of purity. Pure waters practically never give a typical positive result with 10 c.c. and seldom with 100 c.c. of water. For example, in the case of the Metropolitan Water Supply the test was considered superfluous in 1910, owing to the results during five years being almost invariably negative.

The streptococcus[1] test has great potentialities, but a really satisfactory enrichment medium has yet to be found.

Direct cultures on Drigalski and Conradi's medium can indeed be made, but the absence of streptococci from 1 c.c. of water is not sufficient evidence of purity ; when larger volumes are to be dealt with, the cumbrous methods of ' centrifugalisation ' or passing the water through a Pasteur filter, and making a ' filter brushing ' emulsion, must needs be resorted to. Moreover, the almost constant use of the microscope is essential, and not every microscopic appearance is so well-defined as to give certain morphological evidence of the presence of a streptococcus.[2]

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[1] For the number of attributes of fæcal streptococci reference may be made among other reports to p. 484 *et seq.*, *Report of Medical Officer, L.G.B.*, 1903–4. The test as applied to water analysis owes its inception to the writer, but so many difficulties are concerned with its application, the recognition and differentiation of fæcal streptococci and the interpretation of results that the matter can barely be alluded to in this brief note.

[2] The tests for streptococci (e.g. morphology and acid production) are not nearly so definite as those for B. coli (e.g. gas production and indol formation). In the former case the personal equation counts for much more in the interpretation of results than in the latter.

Nevertheless, a typical positive result with the B. enteritidis sporogenes test, and the presence of streptococci indistinguishable from fæcal streptococci would, with the simultaneous presence of B. coli, point strongly to undesirable pollution of a water supply.

As a work-a-day speedy test, the search for B. coli is undoubtedly the best. If the writer's answer to the question submitted to him appears to be somewhat indefinite, it should be remembered that bacteriologists do not commonly condemn waters because of 'conclusive proof' of sewage pollution, but because the cumulative presumptive evidence of contamination is in the absence of contra-indicating circumstances, sufficiently strong to warrant preliminary objection.

*Question* 2.—What bacteriological proof would you consider conclusive that a water is free from such pollution, or so free that it is safe for drinking purposes?

The writer has failed to reveal B. coli in ten samples of a deep well-water, even when as much as 10,000 c.c. were submitted to culture. For practical purposes, the absence of B. coli from 100 c.c. of such a water is reasonably sufficient evidence of safety, and, obviously, the larger the number of samples yielding negative results the more satisfactory is the result. It will be understood, of course, that any judgment based on negative results refers to the quality of the water at the time of collection of the samples and does not necessarily apply to intervening periods or to the future. It should also be remembered as a possible source of contamination that the urine of a 'carrier' case may contain myriads of typhoid bacilli and no B. coli (or hardly any).

The extensive experience of the writer in connection with the examination of *raw* unpurified river-waters, *containing B. coli in considerable number*, has been that the typhoid bacillus and Gaertner's bacillus can practically never be isolated from such waters, despite the use of methods of *proved value*.

In conclusion, the writer thinks that local and other circumstances may properly cause an expert to vary the interpretation to be placed on similar bacteriological results, and that the answer to the two foregoing questions cannot be based on absolute proof, but only on reasonably strong presumptive evidence. From this point of view, a water which *never* contains B. coli in 100 c.c. is to be regarded as safe for drinking purposes; a water which contains B. coli in 100 c.c., in less than half the number of samples examined, occupies an intermediate position, but is probably reasonably safe; a water which contains B. coli in 100 c.c., in a majority of samples, ought to be viewed with some degree of preliminary disfavour.

Waters containing B. coli in lesser amounts, in a majority of samples, cannot, perhaps, with absolute certainty be classed as sewage-polluted; but the presumptive evidence, indicative of their being contaminated, increases to a more than proportionate extent as a 10, a 1, and a 0·1 standard is infringed.

These, however, are arbitrary divisions and, as previously explained, a water should be judged on a *summation of verdicts*.

I am greatly indebted to Dr. Houston for explaining his views so fully, especially as, on the whole, I find myself in agreement with him, and I hope that, in future, analysts will hesitate about condemning a water supply merely because they detect in an odd sample the Bacillus coli, or what they frequently term a coli-like bacillus. Such condemnation often has very serious consequences, and there is the danger of crying 'wolf' so often that no notice will be taken when the wolf is actually at the door. In any case, with the views of Dr. Houston so definitely expressed, such analysts cannot shield themselves behind him by asserting that they are adopting his standard.

When recently examining water supplies on the North American continent, I had the opportunity of seeing also the laboratory methods adopted there, and I was greatly surprised to find what simple bacteriological tests were applied and how greatly their views with reference to the quality of a water differed from ours. The process generally adopted is to add 1 c.c. of the water to be examined to each of 10 tubes of phenolated broth, or of bile-salt glucose broth, and to incubate these for twenty-four to forty-eight hours. If none of these showed signs of active fermentation, the water was regarded as quite satisfactory. If fermentation occurred in a large proportion of the tubes, the water was regarded as unsatisfactory. To be absolutely certain on this point I communicated with Professor C. E. A. Winslow, of the College of the City of New York, who is the acknowledged authority on these matters in the United States, and who (with Dr. Prescott) is the author of their standard work on 'The Elements of Water Bacteriology.' I put to him the two questions which had been addressed to Dr. Houston, and his reply, remarkable for its brevity and preciseness, was as follows:

'In answer to your letter of May 25, I consider that the presence of colon bacilli in all of a series of ten duplicate 10 c.c. samples of water a reasonable proof of the presence of sewage or manurial matter, while the absence of colon bacillus from all ten of such samples is reasonable proof of the absence of sewage matter. Between these two extremes, there is, of course, a region of more or less serious danger.' Apparently Winslow would proceed as just described, but would carry the investigation further to ascertain whether the fermentation was really due to colon bacilli.

(*e*) *Search for Specific Organisms.*—On many occasions a search has to be made for some special disease-producing organism, usually the Bacillus typhosus, rarely the Vibrio choleræ. When the typhoid organism is added to a sample of water, there is, as a rule, very little difficulty in isolating it again and identifying it, but the difficulty of finding it in such impure waters as sewage appears to be at present insurmountable. The search for it in potable waters, in which its presence was gravely suspected, has usually been unsuccessful. On a few occasions, the discovery of its presence in waters suspected to be the cause of enteric fever has been announced, but the proofs afforded have rarely, if ever, been conclusive. One of the most painstaking and careful searches recorded is that made by Dr. Lorrain Smith in connection with the epidemic of typhoid fever in Belfast in 1898, and published in the form of a report. In January 1897 several cases of typhoid fever occurred within the catchment area of the Belfast water supply, and the discharges from the patients were thrown upon a manure heap which drained into an adjoining stream flowing into the reservoir. The bacteriological investigation was undertaken to ascertain whether the infected material had reached the water supply and was in actual operation during the epidemic which commenced in Belfast in the following March. From the examination of the spleen of patients who had died from the disease, Dr. Lorrain Smith found evidence of the presence of bacilli identical with the typical bacillus of Eberth and the Bacillus coli communis of Escherich. He then proceeded to examine the water supply to determine if one or both these bacilli were present in the water, over thirty samples being collected from infected houses. He failed to find the typhoid bacillus in any of these samples, but had no difficulty in isolating a large number of varieties of the Bacillus coli communis. The conclusions at which he arrived were as follows:

1. In the presence in the water of typical bacilli of the coli communis group, we find evidence of contamination with intestinal excreta.

2. Certain of these bacilli exhibit their relationship to the process of infection in typhoid fever, (*a*) by their lethal effect on small animals, (*b*) by showing the reaction of infection when exposed to the blood of typhoid patients.

He thinks that, short of discovering the typhoid bacillus in the water, and thereby giving absolute proof regarding the primary cause of the epidemic, no stronger bacteriological evidence could be adduced in favour of the conclusion that this contamination of the water was one of the causes of the outbreak of the disease in Belfast. In an Appendix (E) he points out that the various experts who examined the Maidstone water during the epidemic in that town arrived at similar conclusions, and he emphasises the importance of the presence of the B. coli by quoting the opinion of Chantemesse and Widal that polluted waters owe their power to produce typhoid infection in a large measure to the presence of the Bacillus coli.

The blood of a large proportion of the typhoid patients in Belfast reacted both to the typhoid bacilli and to the coli bacilli used in his experiments, consequently he adds, 'In the infection of typhoid fever, there is apparently a double process in many instances.' The experiments he records appear also to indicate that there exists a definite relation between the presence of the Bacillus coli communis and the infection of typhoid fever. The races of B coli, which gave this reaction, were isolated from the implicated water, and Dr. Lorrain Smith regards them as being identical with those found in the normal intestine.

A study of this report will convince anyone of the hopelessness of any but the most experienced bacteriologists attempting to demonstrate the presence of the B. typhosus in a drinking water.

The search has been likened to the seeking of a needle in a stack of hay, but this is an exaggeration, as recently devised methods have greatly increased the certainty of the discovery of the bacillus if present in a water.

Dr. Houston in his Research Report to the Metropolitan Water Board has dealt very fully with the detection of the typhoid bacillus and of Gaertner's bacillus in raw river-water, and has shown that by the processes therein described (fifth Report) the typhoid bacillus could be detected were it present in 7 c.c. of raw water, and the Gaertner bacillus if it was present in 18 c.c. At present these appear to be about the limits of delicacy of the method from a practical standpoint (*vide* footnote, page 11, seventh Research Report). It is possible therefore for a potable water to contain over 100 B. typhosus per litre, or 1 B. typhosus in 10 c.c., and yet be incapable of detection. Obviously therefore, when a water is suspected to be causing, or to have caused, an outbreak of enteric fever, negative results obtained upon an examination for the detection of the specific bacillus afford no evidence of real value in deciding whether the water was, or was not, the cause.

When water is the vehicle whereby the typhoid bacillus is introduced into the system, it is fairly certain that the specific contamination was comparatively recent.

In nearly all the waters with which I have experimented, I have found that 99 per cent. of the typhoid bacilli introduced into the water had disappeared in five days and 99·9 per cent. in seven days, and the experiments were made with 'cultivated' bacilli which Houston (seventh Research Report) has shown survive longer in water than the 'uncultivated' bacilli, that is, the bacilli as they are discharged from the human body. He has also shown that temperature has a marked effect, two weeks' storage at 64·4° F. being equivalent to five weeks' storage at 32° F., four weeks at 41° F., and three weeks at 50° F. (seventh Research Report).

The period of storage required to cause the practical disappearance of any typhoid bacilli, which may gain access to a source of water supply, has received consideration by Parliament in two or three recent Bills. In the Lowestoft Water Bill the storage was to be 'continuous flow,' in the Chester Bill the storage was to be 'quiescent.' For the former Bill, Mr. Hehner and myself carried out a long series of experiments both in the river from which the water was to be derived, using drums with ends of gold-beaters' skin, and also with samples of the water kept in bottles in our laboratories. We found it practically impossible to determine when the water, to which the typhoid bacillus had been added,became absolutely free therefrom; but when thousands were added per c.c., the gradual diminution could be traced until we could say no such bacillus was present in 1 c.c. of the sample. No attempt was made to discover the bacillus in larger quantities of the water, it being at that time practically an impossible task, but the results proved that with this particular river-water 99 per cent. of the typhoid bacteria died in less than five days and 99·9 per cent. in seven days or under. In other words, storage for five days improved the water in this respect ninety-ninefold and seven days' storage nine hundred and ninety-ninefold. I have obtained similar results with other river-waters and with deep well-waters from different geological formations. With a spring-water, from the Mountain Limestone, which was suspected of having caused an outbreak of typhoid fever, several series of experiments were conducted, one for determining the vitality of the B. typhosus in the spring-water when standing in the reservoir and another for determining its vitality in the water-mains. The results were as under: Approximate number of B. typhosus added to each c.c. of the water = 20,000.

| Number present in 1 c.c. at end of | Water in flask | Water in piece of main |
|---|---|---|
| 5 days | 2900 | 250 |
| 9 ,, | 910 | 40 |
| 14 ,, | 400 | 4 |
| 19 ,, | 100 | 4 |
| 26 ,, | 0 | 0 |

In another experiment made in flasks containing water, to which 13,800 B. typhosus had been added to each c.c., the bacillus could not be detected in 1 c.c. on the fourteenth day. The more rapid destruction of the B. typhosus in the piece of water-main is marked throughout, but apparently with such a water the mains might continue to contain infected water for over twenty days.

In America many experiments have been made for determining the vitality of the typhoid bacillus in various river-waters, the most important, probably, being those of Jordan, Russell, and Zeit recorded in the *Journal of Infectious Diseases*, Vol. I, No. 4, 1904, and which is reviewed by Houston in his first Research Report, pp. 31–2. They found that the typhoid bacillus disappeared more quickly in celluloidin and parchment sacs submerged in the flowing river-water than in bottles stored in the laboratory. In nine experiments made with lake-water infected with from 500 to 2,000,000 typhoid bacilli per c.c., the bacillus was not found after the eighth day; and in five experiments made with river-water they were not found after the third day.

Much more extended series of experiments have been made with river-waters by Dr. Houston, whose Research Reports should be studied by those interested in the subject. In his sixth Report, he summarises his results as follows:

'The vast majority of the typhoid bacilli perish within one week. Thus in eighteen experiments, with an average initial number of 1,606,673 per c.c. of river-water, the average number one week later was only 531 (99·9 average per cent. reduction). A few, specially resistant bacilli, sometimes described as the "resistant minority," persisted for several weeks. . . . Thus in eighteen experiments the *final* extinction of the typhoid bacillus, as judged by inability to isolate it from 100 c.c. of water, took place in the following periods:

In 4 out of 18 experiments in five weeks.
In 7 ,, ,, ,, ,, six weeks.
In 11 ,, ,, ,, ,, seven weeks.
In 16 ,, ,, ,, ,, eight weeks.
In 18 ,, ,, ,, ,, nine weeks.'

The whole of Houston's results will be found summarised in his seventh Research Report.

The Bacillus enteritidis of Gaertner, a frequent cause of food poisoning, and a bacillus frequently found in the intestine of pigs, and which may possibly be present in the fæces of other animals, has never been found in water so far as I am aware. Houston has examined the raw waters of the Lea and Thames for this bacillus, but he has not been able to detect it with certainty, although on one occasion he isolated a bacillus closely resembling it. As no water analyst is ever likely to have to examine for this bacillus, further reference here is unnecessary.

In the tropics search may have to be made for the bacilli causing dysentery, Flexner's and Shiga's bacilli. In the comparatively few samples of water which have been examined in my laboratory from tropical climates, we have been unable to detect either, and the only experiment we have made therewith has been to ascertain the amount of chlorine necessary to destroy them.

Dr. Darling, working in my laboratory, infected tap-water with 400 bacilli of the Flexner type and found that one part of chlorine per million of water had such an effect in thirty minutes that the bacillus could not afterwards be discovered in 65 c.c. of the water. Using Shiga's bacilli and adding 2575 to each c.c. of water, identical results were obtained. It is very doubtful, however, whether these bacilli could be detected in a sewage-polluted water if present in comparatively small numbers.

The search for Vibrio choleræ is as difficult as that for the Bacillus typhosus. When typical vibrios are added to water there is little difficulty, at first, in isolating and recognising them, but after a time the reactions of the organism appear to become so changed that its identification is practically impossible.

Houston (fourth Research Report) records a number of experiments made with the raw waters of the Lea, Thames, and New River, and confirms the results of previous observers. He summarises his results as under :

'1. Cholera vibrios die very rapidly in raw Thames, Lea and New River water as the result of storage in the laboratory. At least 99·9 per cent. perished within one week, and in none of the experiments could any cholera vibrios (recognisable as such) be found even in 100 c.c. of water three weeks after its infection. In more than half the experiments, the results were negative by the second week.

'2. The isolation of cholera vibrios from artificially infected raw river-water presents no insuperable difficulties, even when the number artificially added is very small, both actually and relatively to the bacteria normally present in river-water.

'3. On the other hand, microbes likely (after careful study) to be mistaken for true cholera vibrios were not found in comparable, but non-infected, river-water samples, examined under precisely similar conditions.'

My experiments with the cholera vibrios have been limited to a research made in order to discover the effect of various quantities of chlorine upon cholera-infected water, and it was found exceedingly difficult to say when the vibrios had actually disappeared, using 100 c.c. of the water for each examination. The cause of this difficulty will be explained in the section dealing with the actual detection of the cholera vibrio.

The following organisms which have been found in water closely resemble the cholera vibrio: Vibrio Metschnikovii, Vibrio proteus (Finkler and Prior), Vibrio danubicus, Vibrio aquatilis, Vibrio albensis, Vibrio berolinensis. Besides these there are, apparently, a number of allied organisms found in sea-water.

(*f*) *Organisms producing Sulphuretted Hydrogen.*—Very rarely, indeed, does any potable water acquire an odour or taste from the presence of bacteria. Such changes are usually brought about by the multiplication of higher forms of life. I have, however, had to examine waters having an odour of sulphuretted hydrogen, which odour I have attributed to the reduction of sulphates by bacteria. In Essex and elsewhere natural waters occur, having a faint odour of this gas, and well-sinkers from time to time encounter it in their boring or sinking operations. In some cases the sulphuretted hydrogen may be due to a purely chemical reaction; but in many the more probable explanation is the decomposition of sulphates or of albuminous matter by low forms of vegetable life. The odour is so often met with in marsh waters that it was at one time surmised that the vegetable matter in the water was capable of acting upon iron pyrites, with the formation of sulphuretted hydrogen. No doubt the organic matter is the source of much of the sulphuretted hydrogen found in sewage, but some is probably derived from the sulphates present. The gas is generally abundant in stale sewage, kept from contact with the air. Sewage containing brewery yeast is especially prone to this form of decomposition.

Using a gelatine medium, to which a little sodium ferro-tartrate rendered alkaline with sodium carbonate has been added, many organisms will be found to produce a black discoloration, due to the formation of ferrous sulphide. According to Lehmann and Neumann,[1] the following bacteria produce sulphuretted hydrogen:

| In moderate amount | Abundantly | Very abundantly |
|---|---|---|
| Streptococcus pyogenes. | Staph. pyog. aureus. | B. typhosus. |
| Sarcina flava. | B. acidi lactici. | Bt. vulgare. |
| B. diphtheriæ. | B. coli communis. | Bt. murisepticum. |
| B. pseudo-diphtheriæ. | B. Zopfii. | B. erysipelatos. |
| | B. Megatherium. | B. mesentericus. |
| | | B. tentani. |
| | | B. Chauvoei. |
| | | B. œdematis maligni. |
| | | Vibrio choleræ. |
| | | V. danubicus. |
| | | V. berolinensis. |

As many of these organisms are found in sewage, the production of sulphuretted hydrogen therein is probably explained.

Certain of the Essex waters, with an odour of this gas, when added to such a medium (containing gelatine and iron), blacken the jelly after a time, but I know nothing of the characteristics of the organisms producing the reaction.

Beijerinck[2] has shown that the motile obligate anaërobic Spirillum desulfuricans, which has only slight morphological characteristics, can decompose sulphates. Zelinsky[1] has described a motile bacillus, found in ooze from the Black Sea, which gives rise to sulphuretted hydrogen, and Holschewnikoff found a slightly motile bacillus in the mud from the Wiesbaden filter beds with the same properties, and which he named Bacterium sulphureum. The descriptions given of these bacteria are very meagre, quite insufficient for their future identification. The organisms shown on Plate XXXII were abundant in a water derived from the chalk, which had a distinct odour of rotten eggs, but I was unable to prove that the sulphuretted hydrogen was due either to the life processes or decay of any one of them.

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[1] *Bacteriology*, Table I.

[2] Lehmann and Neumann's *Bacteriology*, p. 77.

Waters with an odour of sulphuretted hydrogen are too disgusting in character to be of use for domestic purposes. I have known persons use a polluted pond-water rather than water from a well of considerable depth which had a faint odour of this gas, but was otherwise of excellent quality.

Odours due to Crenothrix, Beggiatoa, &c., have been referred to in a previous section.

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[1] Frankland's *Micro-organism in Water.*

# PART III

## *ANALYTICAL PROCESSES AND METHODS OF EXAMINATIONS*

## CHAPTER XI

### COLLECTION OF SAMPLES OF WATER

The quantity required for chemical examination will vary according to the method of analysis adopted. Where it is merely desired to make a so-called sanitary analysis a litre is quite sufficient, provided no accident occurs during the carrying out of the processes. For most purposes 2 litres are ample and allow a margin for contingencies. The ordinary stoppered Winchester of pale green glass holds this quantity and answers very well. Dark-coloured bottles are to be avoided. I prefer strong white glass bottles and use two sizes, 1-litre and 2-litre respectively. The bottles should be used for no other purpose, and be rinsed with strong acid, and afterwards with water, before being sent out. For carrying about and sending by rail light wicker-work cases or wooden boxes in which the bottles stand upright are the safest and best. These can easily be made so as to be secured with a padlock if desired.

Wherever possible the bottle should be rinsed out two or three times with the water to be examined, before being finally filled. If this cannot be done the bottle should be well drained. The stopper should not be laid down, but kept in the hand and rinsed with the water before being inserted. The bottle should not be entirely filled, a small amount of air should be left in it. If completely filled, and the stopper firmly inserted, any increase in temperature will cause the neck of the bottle to crack, and a decrease of temperature usually wedges in the stopper so tightly that it is difficult to remove it without a fracture.

Unless absolutely unavoidable, no funnel or jug should be used in filling the bottle, and the bottle should be so held that the water does not come in contact with the hand before entering.

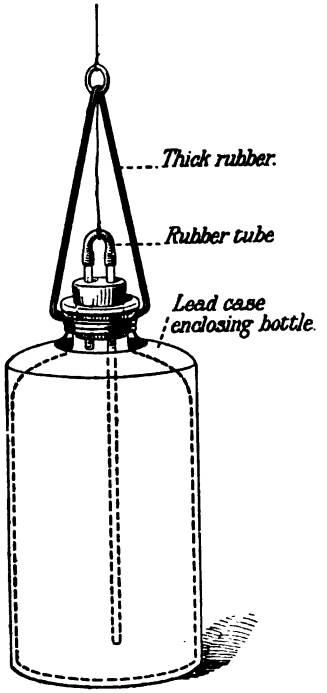

FIG. 3

In taking a sample from a tap or pump, water should be allowed to run to waste for a few minutes before filling the bottle, unless it is desired to ascertain whether the water is affected by standing in the mains or pump pipe. If such is the case it is best to take the sample first thing in the morning before any has been drawn for other purposes. In taking samples from springs and rivulets it is often necessary to make an excavation sufficiently large to hold the hand and bottle, and allow sufficient time for all matter disturbed to be washed away before taking the sample. Where the sample must be taken by immersing the bottle, as in ponds, cisterns, reservoirs, rivers, many wells, &c., I often use the simple apparatus shown in fig. 1. It is very easily put together, and can be used with equal facility for obtaining water from a great depth in a bore tube or well, and from an open tank or running stream.

A stoppered bottle of any size can be used, provided the leaden cylinder, partially closed in at the top, will go over it. The glass stopper is removed, and a rubber cork with two perforations inserted in its place. Through one perforation passes a piece of glass tubing about two inches long, and through the other a longer piece of tubing reaching to near the bottom of the bottle, and projecting about an inch above the rubber stopper. The projecting tubes are connected by a piece of rubber tubing about two inches long. The bottle is suspended by means of a stout band of rubber about one foot long, such as is used for door springs, the free ends being secured tightly to the neck of the bottle by cord or catgut. A metal loop or swivel connects the rubber suspender with the cord or catgut used for lowering the bottle into the water. The loop or swivel is connected with the short piece of rubber tubing uniting the two glass tubes by a piece of string or catgut, of such length that when the bottle is suspended there is no pull upon the rubber tube, which, however, can easily be jerked off when a sharp pull is given to the suspending cord. The apparatus being arranged, it is lowered to the required depth, a sharp jerk is then given to the suspending cord, when the rubber tube is detached. Water enters through the longer tube and the air is expelled through the shorter tube. Bubbles of air can be seen or heard rising through the water until the bottle is full, or until only a little compressed air remains in the neck of the bottle. As the apparatus is raised, the air thus imprisoned expands, and prevents water from nearer the surface entering. Catgut serves better than cord for suspending the bottle, and if this is marked off in yards the depth to which the bottle has descended is known. Cord is useless for this purpose.

The points requiring chief attention are to see that the rubber stopper is tightly inserted, and that the small piece of rubber tubing can be easily detached by a slight jerk.

Although this apparatus is generally useful it cannot be used when a sample has to be taken from a depth of 300 feet below the surface of the water. The pressure is there so great that the bottle is crushed in, the explosion sounding like the discharge of a gun in the well. To get over this difficulty a special apparatus was made, and it has proved so useful that the use of the glass bottle in taking samples is no longer preferred. The diagram on p. 262 will render a description of the apparatus intelligible. *A* is a copper cylinder tinned inside and out, 5 inches in diameter and holding 2 litres or a little over. *B* is a leaden weight attached by means of a screw to the bottom of the cylinder. *C* is a small ring fixed to the upper domed surface for attachment of the cord. *D* and *E* are two turned copper tubes about ½ inch in diameter, one passing to the bottom of the cylinder and the other terminating just inside the cylinder. Taps with long handles and ½-inch bore are affixed at the same level, and when the levers are horizontal the taps are closed. *H* is a piece of lead pipe with a flange at the bottom. This is threaded on the cord.

The cylinder is lowered into the water to the desired depth, the leaden weight *H* being retained in the hand. When the bottle has reached the position from which the sample of water has to be taken, the weight is allowed to drop. It strikes the top levers into a nearly vertical position. Water then enters the cylinder at *D* and the air escapes from the end of *E* at a higher level than *H*, so as not to cause any disturbances of the water entering at *D*.

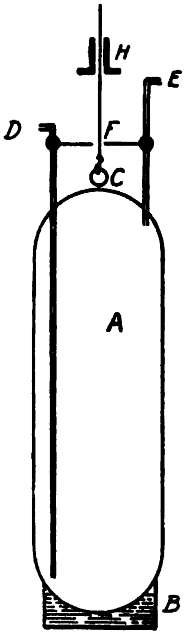

Fig 4

When air bubbles cease to rise, the apparatus is withdrawn and the contents can be run into a bottle from the nozzle *E*, air being admitted at *D*.

By attaching one nozzle to the steam tap from a pressure boiler, the whole apparatus can be sterilised in a few minutes by the current of high-pressure steam.

The apparatus can be used in a boring of 6 inches diameter. A smaller size would be required for tubes of lesser diameter.

When called upon unexpectedly to take a sample of water from a well in which the water-level was about 100 feet below the ground-level, and where it was desirable to fill the bottle some feet below the water surface, on account of the admixture with rain-water, I succeeded by the following simple expedient. A 7-lb. weight was borrowed and attached by a cord to the bottle. Some balls of twine were obtained. One cord was securely attached to the neck of the bottle, and this lashed to the middle of a broomstick placed horizontally. The glass stopper was greased so that it could easily be pulled out and a second cord attached to it. Upon lowering the bottle the broomstick prevented it revolving, and the two cords did not therefore intertwine. When the bottle had sunk to the requisite depth, the stopper was removed by briskly jerking the cord attached thereto.

Probably the following device used by some well-sinkers would have been equally successful. The cord is tied round the neck of the weighted bottle, and then at a distance of 2 or 3 inches a loop is passed round the base of the stopper. The stopper is tightly inserted and the bottle suspended by the stopper. When sunk to the requisite depth, a sharp jerk on the cord should pull out the stopper and the bottle fills with water. It is not always successful, especially if the bottle is sunk to any considerable depth.

Occasionally water has to be obtained from 2-inch tubes driven for experimental purposes. In such cases the apparatus shown in fig. 2 and made out of a 200 or 250 c.c. pipette answers very well. *A* is a piece of lead pipe sufficiently heavy to sink the pipette. *B* is a perforated rubber stopper fitted on the upper end of the pipette and covered with a narrow strip of oiled silk. This is secured by a string tied tightly round the stopper, and a loop should be left so that the apparatus can be attached to a cord. When the tube is lowered the water enters, displacing the air through the oiled-silk valve. When raised the pressure on this valve closes it securely and prevents the water escaping..

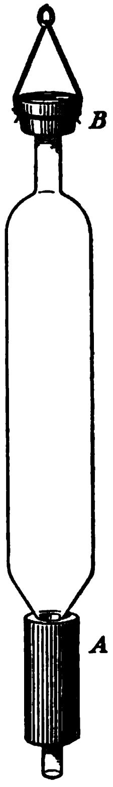

FIG. 5

When a water has to be examined bacteriologically, special precautions must be taken to prevent the slightest risk of contamination. If collected in bottles these should be small (250 to 500 c.c. capacity [1]), and have been sterilised by rinsing first with strong sulphuric acid and afterwards with boiled water, and finally by exposure to current steam for from fifteen minutes to half an hour. They are then allowed to cool in the steriliser, the stoppers are inserted, and the whole wrapped in sterilised wool. The water collected in such bottles can be used for determining the number of bacteria present and for the examination for particular organisms, such as the Bacillus coli communis or the Bacillus enteritidis sporogenes. If it is desired to determine the number of bacteria present in a water, the sample should be taken straight to the laboratory and gelatine plates at once prepared. If there must be a delay even of a few hours, the bottles should be stored in ice. Special samples may be taken for this purpose in small sterilised tubes. The method of making and using these tubes is thus described by Professor Sheridan Delepine:[1]

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[1] Occasionally a litre of water is required.

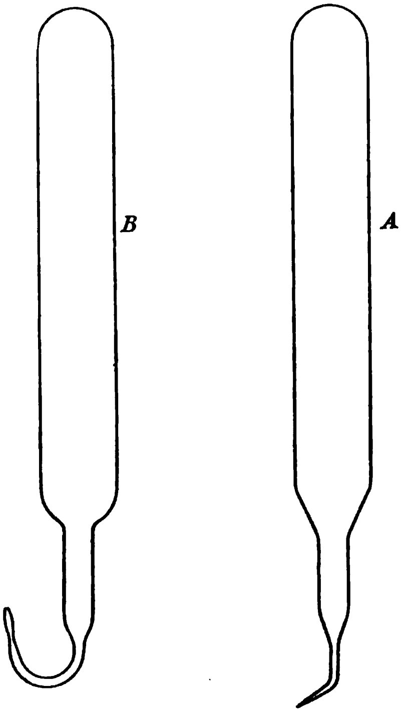

FIG. 6

'Tubes made of moderately thick glass ¾ inch in diameter are closed at one end like test-tubes. The other end is drawn to a point, as shown in fig. 3 *A*. These tubes are 7 to 8 inches in length, the wide part occupying about 6 in. They can hold about 20 cubic centimetres of water. They are prepared from tubing which has never been used, and has been thoroughly cleansed. The tube is sterilised by dry heat at the time of making. The drawn end forming the neck measures about ½ inch in diameter; about 1 inch of the end is further drawn so as to reduce it to $\frac{1}{30}$ inch in diameter. The tube being so prepared is, after being allowed to cool, gently warmed again, and its open point immersed in pure water. As the tube cools, water is drawn into it on account of the contraction of the cooling air. When about 1 cubic centimetre has been thus sucked in, the point is removed from the water.

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[1] 'Bacteriological Survey of "Surface" Water Supplies': *Journal of State Medicine*, vol. vi. p. 194.

'The water is then boiled rapidly in the tube until it has practically all been reduced to steam; the point is then quickly sealed in the flame of the blowpipe, the steam still escaping. (The flame heating the water is of course removed as soon as the sealing process has begun.)'

Tubes thus prepared may be kept in aluminium tubes closed at each end with rubber stoppers, and the metal tubes and contents sterilised in the usual way. When one of these tubes is to be used, the point is passed through the flame of a spirit lamp and then immersed ½ to 1 inch below the surface of the water, and then nipped off by aid of a pair of sterilised forceps. As soon as the tube is nearly full the point is removed and sealed in the flame of a spirit lamp, preferably by aid of a blowpipe.

When water has to be taken from a tap, a sterilised wide-mouthed bottle may be filled, and samples taken therefrom in the vacuum tubes in the manner described. Should it be desired to take samples from points difficult to reach, vacuum tubes with a bent neck, as in fig. 3 *B*, may be used. The tube can be fixed at the end of a rod, and the point broken off by a jerk of the twine attached thereto.

For collecting samples from wells, bore-tubes, &c., some form of apparatus may be used which permits of the point of the vacuum tube being broken off whilst the tube is suspended in the water; but it is generally more convenient to fill a sterilised bottle in the way described, and, if necessary, vacuum tubes can be filled therefrom. Inasmuch as 100 c.c. of the water may be required in the search for the B. coli, it is much better to obtain a larger quantity in a bottle, then a vacuum tube can be filled therefrom and put in the ice case, the contents being used merely for the enumeration of the bacteria present. In this case it is unnecessary to put the larger sample in ice, as no increase of B. coli will occur during transit to the laboratory.

When the gases contained in a water have to be determined, special care must be exercised in collecting the samples. Usually the samples are taken in the special tubes or flasks which will be used for the determinations. When the water is being taken from a tap a piece of tube should be connected to the nozzle and the water allowed to enter at the bottom of the flask and the flow continued until a good deal has run to waste. Whilst the water is still flowing the bottle can be slowly withdrawn and the stopper inserted. When the water has to be taken from a tank, stream, or well, the following device of Mr. Phelps [1] may be used. Two wide-mouthed bottles are required, one of not less than twice the capacity of the other. Both are fitted with doubly perforated rubber stoppers, through one hole of which a glass tube passes to the bottom of the bottle and another just projects through the stopper. The bottles may be placed side by side or the smaller one may be placed below the larger. The long tube of the larger bottle is connected by a piece of stout rubber tubing with the short tube of the smaller bottle. When weighted and sunk, water begins to flow into the smaller bottle, air escaping from the larger. When sunk to the proper depth and allowed to rest for a few minutes, or until air bubbles cease to arise, both bottles are full of water, but that in the smaller bottle will not have been in contact with air. When withdrawn a solid stopper must be inserted in the smaller bottle. Mr. Phelps says that 'although devised primarily for the collection of samples for the "oxygen dissolved" determination, the apparatus may be used for a variety of purposes. The writer has frequently used the water in the smaller bottle for the determination of the micro-organisms.'

When samples of water are being taken from different sources for comparison, they should be collected within as short a space of time as possible. This especially applies where the sources are likely to be affected by rainfall or other causes of variation in quality.

Bottles in which samples are collected should be capped with clean wash-leather or linen, and duly labelled to secure identification. If such identity has to be afterwards proved, the string or tape securing the covering should be so sealed that the bottles cannot be opened without breaking the seal.

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[1] *Technology Quarterly*, Vol. 15, June 1902.

Care should be taken to record on the spot every detail which may have any bearing upon the results of the analyses to be undertaken, or which may be of importance in connection with the taking of the samples, or be of general or scientific interest.

In taking a sample from a stream, the following points should be recorded:

1. Date and time when sample is taken.
2. In whose presence.
3. Exact point marked on Ordnance map.
4. Whether at or near middle of side, and which side.
5. Depth below surface.
6. Weather at the time, and particulars of any recent rainfall.
7. Whether the level of water is above or below average.
8. Observations with reference to any possible sources of pollution in the vicinity.

If a single sample only is being taken, it should be collected from beneath the surface near the middle of the stream.

In taking samples from an open well, record 1, 2, 3, as above, and in addition—

4. Approximate ground surface-level above O. D.
5. Depth from ground level to surface of water.
6. Depth of water in well, and depth at which sample is taken.
7. The mode of construction of the well, including its covering.
8. Whether the appearance of the water is affected by heavy rains.
9. Any indications of pollution, discoloration of sides, &c.
10. Character of the surroundings, proximity to drains, sewers, stables, dustbins, piggeries, churchyard, &c.
11. And, if possible, section of well, and
12. Yield of water and effect of pumping.

As the character of the water in open wells often varies at different depths, it is best to lower the bottle rather rapidly under the surface of the water, so that it may, when filled, contain water from all parts of the well.

In taking samples from a large reservoir, one should be taken near the point of entry, and another near the exit of the water. If only one sample is to be collected, it is best to take it from beneath the surface, just over or very near the mouth of the trunk main or conduit.

When taking a sample from a house-tap connected with a public supply, it should always be noted whether the tap is directly connected with the main or with a cistern. If with the latter it should be examined, and particulars thereof recorded. The position of the main should also be noted, and the proximity to a dead-end or ball-hydrant ascertained if possible.

When samples of water are received for analysis, and there is any doubt about the way in which they have been collected, or about the cleanliness of the bottles used, or when the samples are sent in bottles closed with unclean corks, it is best to communicate with the sender and offer to despatch suitable bottles for fresh samples. The following is the form which I generally use, the sender of the sample being requested to furnish the information required.

### PARTICULARS REQUIRED CONCERNING SOURCE, &c., OF WATER SENT FOR ANALYSIS

1. Name and address of person desiring the analysis.
2. Is a Chemical or Bacteriological examination required or both ?
3. Reasons for wishing an analysis—if the water is suspected of causing ill-health, the symptoms should be stated.
4. Exact place from which the sample was taken. If from a house-tap, say whether drawn from a cistern or directly from the main.
5. State whether a well, spring, or stream, or a public supply.
6. If a well, state the depth.
7. If a well, state whether the bricks are set in cement, or are cement-lined or puddled behind.
8. State nature of subsoil from which water is derived.
9. State whether there are any drains or cesspools, or other possible sources of pollution, and distance from source of water.
10. Does the water become affected in appearance, odour, or taste, after a heavy rain ?
11. Date on which sample was taken and sent.

When sending a sample of water for analysis, the above form should be filled in and sent by post.

Suitable bottles, thoroughly cleansed and ready for filling, will be sent on application.

In filling the bottles, carefully carry out the instructions given below for collecting the sample of water.

Samples should be dispatched immediately after being collected, and bacteriological samples should be packed in ice. Special boxes for the purpose will be sent when required.

To this form are attached the directions (see page 270) for securing the proper collection of the samples of water.

## INSTRUCTIONS FOR COLLECTING SAMPLES OF WATER FOR ANALYSIS

1. The water should be collected in white glass bottles having well-fitted glass stoppers. Bottles holding about half a gallon of water are necessary for the chemical analysis. Smaller quantities are sufficient for the bacteriological examination.

2. When the bottles have been forwarded from the laboratories, it is unnecessary to rinse these before taking the sample of water, the removal of the stoppers and filling direct is all that is required. In the case of clients using their own bottles, these should be thoroughly cleansed, filled thrice with water, and thrice emptied, before collecting the sample.

3. In collecting from a pipe, the tap should be turned on at full and the water allowed to run to waste for at least two minutes (timed by a watch) before the sample is taken, in order to prevent impurities in the pipe being collected in the specimen. If a bacteriological analysis is to be conducted, the nozzle of the tap should be flamed (i.e. by dipping a small piece of cotton wool in methylated spirit, lighting same, and holding the wool, by means of tongs, close to the nozzle until the whole tap is unbearably hot) and then cooled by the running water for a few minutes before the bottle is filled.

4. In collecting from a stream, lake, spring or well direct, the stopper should be inserted in the bottle and the whole bottle placed well under the surface of the water, the stopper removed and the bottle filled. This method prevents the inclusion of surface water.

5. In collecting the samples, hold the bottles with the hand as far away from its neck as possible.

6. The stopper should be secured by covering with a piece of clean linen.

7. After stoppering, the bottles should be labelled, stating the source, date, and time of collection. It is generally desirable to fill in all the particulars in the blank spaces of the labels supplied with bottles from the laboratory.

When the water is derived from a deep well, the following details should be obtained, if possible, and studied by aid of the geological map of the district.

### PARTICULARS RELATING TO THE SOURCE FROM WHICH THE WATER WAS DERIVED

Information supplied by

Date

Position of Well, 1-inch Ordnance Map

Ground-level at Well

Depth from ground-level to surface of water.
(rest-level)

Section of Well

Surroundings likely to affect the character or purity of the water:

If the water varies in appearance or character, state under what circumstances.

Approximate yield of Well

Occasionally further inquiries have to be made, to enable a reliable opinion upon the character of the source to be given. The nature of these inquiries will depend upon the source, and may be inferred from a consideration of the sections referring to the examination of the various sources from which water supplies are derived.

# CHAPTER XII

## THE PHYSICAL AND CHEMICAL EXAMINATION OF WATER FOR SANITARY PURPOSES

In very many cases, after the examination of the source from which a water is derived, a few simple tests will show whether the water is or is not suitable for domestic purposes. Where difficulties arise from a properly equipped laboratory not being available, and anything like a complete analysis being impossible, practically all the information necessary may be obtained by an analysis made as described by me in a pamphlet entitled 'A Simple Method of Water Analysis.' This method was originally designed, more especially, for the use of Medical Officers of Health in Rural Districts. The chemicals used are in the form of 'soloids,' and the processes require no special laboratory, and only the simplest possible apparatus. In fact, both chemicals and apparatus can be packed in a small case or bag, and be easily carried in the hand.

Usually, however, a more complete examination is desired, involving quantitative estimations by volumetric processes, together with qualitative tests for the presence of certain objectionable substances. Many Chemists and Medical Officers of Health are satisfied with an analysis which includes the estimation of the chlorine, the total hardness, the free and albuminoid ammonia, and tests for the presence of nitrites and nitrates. Others estimate also the nitrates and the 'oxygen absorbed,' and test for phosphates and objectionable metals. Others again make a rule of determining the total solids, since this affords a check on the results of the analysis, any large difference between the total solids and the sum of the chlorides, nitrates, carbonates and sulphates (the two latter judged from the hardness results), indicating the necessity for further examination.

The results obtained are expressed in so many different ways that the comparison of analyses by different persons is often difficult and troublesome. Thus some express the nitrates present in terms of nitrogen, others as nitric anhydride, and others, again, as hydrogen nitrate or nitric acid. The frequent use of the word 'traces' also leads to confusion, as it undoubtedly is used differently by different people. Usually it signifies 'too small a quantity to be capable of determination'; but often it is used merely to indicate that a small amount of the substance is present, but that this amount was not estimated. The word ought to be used as rarely as possible, and then only when its significance cannot be misunderstood.

Again, the results may be given in grains per gallon, parts per 100,000 or parts per million, or some results may be entered in grains per gallon, and others in parts per million in the same analysis. It is, in my opinion, best to express all the results in parts per 100,000, as being the most scientific and most generally useful. To convert these results into grains per gallon it is only necessary to multiply by 0·7, while multiplication by 10 gives the results in parts per million.

In the majority of cases all the information required to form an opinion upon the character of a water can be obtained by determining the chlorine in chlorides, the nitrogen in nitrites and nitrates, the hardness, the free and organic ammonia, and by testing for the presence of nitrites. When necessary these can be supplemented by ascertaining the total solids and the oxygen absorbed, and applying tests for the presence of salts of iron, lead, and zinc. For the above reason I purpose describing first the various methods of making these determinations, reserving for a separate chapter the description of the processes for making an analysis of the saline constituents.

## I.—PHYSICAL EXAMINATION

Under all circumstances it is desirable to note certain physical characters of the water, the colour, brightness or turbidity, and odour, while sometimes it may be desirable to ascertain whether the water has any appreciable taste.

(*a*) **Odour.**—When the stopper is first removed from the bottle containing the water an odour may be apparent. If not, put about 250 c.c. into a half-litre flask, warm to near 100° F., shake vigorously, remove the stopper, and again smell. If any odour is detected, describe it if possible.

The various odours are often difficult to describe, but the A.P.H.A.[1] suggest the following classification: Vegetable, Aromatic, Grassy, Fishy, Earthy, Mouldy, Musty, Disagreeable, Peaty, Sweetish, and recommend that the intensity be expressed by numerals varying from 0 to 5, 0 signifying 'no odour perceptible,' and 5 'an odour so strong that on this account alone it would be absolutely unfit to drink.'

Other odours, as of gas, tar, &c., may be similarly recorded.

(*b*) **Colour.**—This is usually ascertained by filling a tube two feet in length, of white glass and with a flat end, and looking through the column of water at a sheet of white paper. It may be compared, if desired, though this is rarely necessary after a little experience, with a column of distilled water in a similar tube. Where the turbidity is sufficiently marked to mask the colour of the water, filtration may be resorted to; but, as a rule, it suffices to note the colour of the turbid liquid.

By using a special tintometer, the exact depth and tint of colour can be determined. An apparatus which was until recently used in the examination of the London waters consisted of two hollow wedges, one filled with a brown and the other with a blue solution, both of known composition. These wedges were made to slide across each other in front of a circular aperture in a sheet of metal. By this means any desired combination of brown and blue could be produced. Each prism was graduated along its length from

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[1] American Public Health Association.

1 to 40, the figures representing in millimetres the thickness of the said standard solution at that particular part of the prism. Just below the level of the prisms and in a horizontal position was a 2-foot tube to be filled with the water under examination. This tube had in front of it a circular aperture of the same size as the one in front of the prisms.

The stand supporting the prisms and water tube was placed horizontally in front of a uniformly lighted window, fitted by preference with ground glass. (Two ground-glass caps are supplied to take the place of the ground-glass window.) The observer, standing, say, three or four feet from the instrument, sees two luminous discs, the lower one illuminated by light which has passed through two feet of the water under examination, and the upper one illuminated by light which passes through the respective thicknesses of the brown and blue solutions.

By sliding the prisms sideways, one way or the other, so as to obtain a colour produced by the mixture of brown and blue, the tint depth seen in the lower disc could be imitated with considerable accuracy. A metal pointer fixed over the centre of the upper disc indicated on the prism scales the thickness, in millimetres, through which the light had passed to produce a colour which corresponded to that seen through two feet of the water. The results were recorded in the following way: Brown 31, blue 20. This indicated that the colour of a stratum of two feet of the water under examination was represented by an admixture of these colours in the proportion stated.

The tintometer usually employed, however, has two tubes, one of which is filled with distilled water and the other with the water to be examined. In a black box at one end of the tubes is a mirror placed at an angle of 45° and reflecting light transmitted by the tubes upwards through two cylindrical glasses, one of which, that belonging to the tube containing the water being examined, contains a little distilled water, and the other a brown solution of potassium bichromate and cobalt sulphate (*vide* formulæ in Appendix). Enough of this solution is poured in to match the colour of the examined water, as seen by looking down through the two short cylinders. Light is transmitted through the tubes by reflection from a plate of white glass fixed at the end of the instrument.

The colour being imitated, the depth of the liquid is measured in millimetres and recorded. The two feet of distilled water has apparently approximately a blue tint representing 20 on the older form of tintometer, so that assuming the water examined to require 20 millimetres of bichromate solution to imitate the colour, it should be entered as blue 20, brown 20. Usually, however, only the number representing the brown is recorded.

The water must always be filtered before being examined, otherwise any turbidity present will interfere with the results.

In this country little stress is laid on the determination of the colour, but in America the colour and degree of turbidity of the chief public water supplies are systematically recorded, and quite a number of special instruments have been devised for these purposes.

(*c*) **Brightness or Turbidity.**—Viewing a considerable bulk in a colourless glass flask, the water may be described as 'brilliant,' 'bright,' 'clear,' 'dull,' 'slightly opalescent,' 'markedly opalescent,' or 'turbid.' Any visible particulate matter should be noted and examined under the microscope.

Occasionally it is desirable to estimate the amount of matter in suspension. If this is considerable, it can be ascertained by subtracting the weight of the residue left by the evaporation of 100 c.c. of the filtered water from the weight of the residue from the same amount of the unfiltered water. Usually, however, the amount is too small to be measured in this manner, in which case one or other of the following methods may be used:

*α*. Filter about a litre of the water through a very small filter made of specially hard paper. Wash the filter with distilled water. Make an opening with a sharp thick needle through the apex of the filter, and wash the deposit into a small tared platinum or porcelain dish. Evaporate off the water and weigh the residue.

*β*. The following method was adopted by Professor Boyce and others in their examination of the Severn waters for the

Royal Commission on Sewage Disposal. It unfortunately requires the use of a large centrifugal machine. 600 c.c. of the water are centrifugalised, the clear liquid pipetted or siphoned off, and the remainder transferred to a small specially constructed tube, the bottom of which is drawn out like a thermometer tube and graduated in 0·01 c.c. 'The glass is filled and centrifugalised for 2½ minutes in a hand centrifuge making about 2000 revolutions per minute; the result is that the deposit is forced into the graduated stem and the amount can be easily read off.'

γ. The above processes may be combined, the water being passed through a small filter as in *a*, and the residue washed into one of the graduated tubes, and the amount estimated as in β. The deposit thus obtained can afterwards be submitted to chemical and microscopical examination.

The amount of matter in suspension producing a mere opalescence in a water is generally so small that its accurate estimation is impossible. For this reason, in America, instruments called 'turbidimeters' are used. Probably the best of these is one devised by Mr. C. Anthony, and described by him in the Journal of the New England Waterworks Association.

Mr. C. Baker, scientific instrument manufacturer, 244 High Holborn, London, W.C., made for me a modified form of this turbidimeter.

It consists of two parallel tubes, one of which, of standard length, viz. 50 centimetres, closed at the ends by plates of glass, contains the water to be examined, and the other a Nicol prism.

The ends of these tubes are covered with caps containing ground-glass screens of the same density. These two sources of light are examined through an eyepiece containing another Nicol prism, and by employing a rectangular prism between the eyepiece and the two tubes the field of view is seen nearly dechromotised, one half being illuminated from light coming through the tube containing the water under examination, whilst the other half receives light from the tube containing the Nicol prism. By rotating the eyepiece the illumination of the latter half of the field, seeing that the light has already passed through a Nicol prism, can be varied until it matches the half receiving light through the standard thickness of water under examination. To the eyepiece a pointer is attached which rotates through 90° and indicates the amount of turbidity of the water to a rational scale, in which 0 represents perfect transparency and 1 total obscuration. When water of very great turbidity is to be examined, the tubes can be unscrewed and the lengths reduced to 25 or 12½ centimetres, when the results read must be multiplied by 2 or 4 to bring them to the standard length of 50 centimetres.

If the turbidity of the water is such that even with the 12½ centimetre tube length it is too opaque to permit of an accurate determination, recourse must be had to diluting it with an equal or double volume of distilled water, when the results must be still further multiplied by 2 or 3 to bring them into due relation with the standard tube length of 50 centimetres.

The instrument can be used with practically any illumination, and is packed in a mahogany case, which also serves as a stand.

This instrument is used in the laboratories of the Metropolitan Water Board for examining river-waters, but Dr. Houston does not record the tintometer degrees. He made definite mixtures of saccharated carbonate of iron B.P. with distilled water, and read off the results on the scale of Anthony's turbidimeter. These were plotted out so as to obtain a curve and figures for all intermediate readings. The scale on the turbidimeter is then given a value in terms of saccharated carbonate of iron. Initially this work is a little troublesome, but once done it need never be repeated whilst the same instrument is in use. Dr. Houston informs me that the value for small readings cannot be relied upon, but that the method works well when waters are really turbid, and it is only on such occasions that the results are of any value. If a mixture of 1 gramme of saccharated carbonate with 1 litre of water be made, each 100 c.c. would contain 100 mlgr. of the carbonate, and the turbidity could be expressed as 100. If the degree of turbidity only equalled that of 8 mlgr. of the carbonate per 100 c.c. the turbidity would be 8, &c. This strength (one gramme to a litre) is a convenient one for use in plotting the curve from the tintometer results. It could, of course, be used without a tintometer, as in the silica method generally adopted in the United States, next to be described, the saccharated carbonate of iron taking the place of the Fuller's earth.

In the United States I found the silica method in use in every laboratory visited. The silica recommended is Fuller's earth in the finest state of division. The silica standard is made as follows:[1] One gramme of the Fuller's earth is mixed with 1 litre of distilled water and forms the stock suspension, which should have a turbidity of 1000. The suspension is tested, after diluting a portion of it with nine times its volume of distilled water with a wire, in the following manner. A vessel, at least 20 centimetres in diameter and 15 deep, is filled with the liquid. A piece of bright platinum wire 1 millimetre in diameter is attached to the end of a rod, so that 2·5 cm. project at a right angle. The rod is marked at a point cm. (100 millimetres) above the platinum wire.

The vessel containing the turbid standard is placed in a good light, but not in direct sunlight, and the rod lowered until, when looking perpendicularly, the wire becomes invisible. This should occur when the wire is 100 mm. below the surface of the water. If the degree of turbidity is not correct, more silica or more water must be added until the standard is attained.

From the 1000 standard others are prepared by dilution with distilled water. For turbidity readings below 20, standards of 0, 5, 10, 15, and 20 are prepared and kept in bottles exactly similar to those used in collecting the samples, or in bottles exactly the same as those containing the water to be examined. For readings above 20 standards of 20, 30, &c., up to 100 may be kept in tubes approximately 2 cm. in diameter.

Comparisons should be made 'by viewing them sideways towards the light, looking at some object and noting the distinctness with which the margins of the object can be seen.'

Determinations of turbidity are really only useful when waters from the same sources are being periodically examined, or where turbid waters are actually being compared for any reason. Where silica standards have been prepared, the turbidity can be estimated rapidly and with sufficiently approximate results. If a turbidimeter is available, the process is nearly as rapid, but experience is required in using the instrument, as the tints of the two discs never correspond accurately and the point of equal obscurity varies with the views of the person using the instrument.

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[1] *Standard Methods of Water Analyses.* American Public Health Association, 1912.

In any case, where an attempt is made to express by figures the degree of turbidity, the method and scale adopted should be indicated.

(*d*) **Taste.**—When a water has an odour there is in many cases a corresponding taste, subjective or objective. This may be observed either by rinsing out the mouth with the water or by actually swallowing it. The latter course is obviously not always to be recommended. Where there is no characteristic odour, as of peat, and a taste is observable it may be described as 'peaty,' 'brackish,' 'mawkish,' 'saline,' 'ferruginous,' 'flat or insipid,' 'peculiar,' &c., and the degree indicated, if necessary, by the adverbs 'slightly' or 'very.' The best types of water would be described as 'palatable' or 'very palatable.'

(*e*) **Temperature.**—Occasionally it is desirable to record the temperature of a water as it rises from its source and to compare it with the air temperature at the same time or with the temperature of other waters. Latterly I have recorded the temperatures of all samples taken directly from deep wells in Essex in the hope that their study may ultimately give information which may be of value. The results, at present, seem inexplicable, deep wells not far apart yielding waters differing considerably in temperature. I have observed, however, that in the waters with the higher temperature the multiplication of bacteria is more rapid than in the waters with a lower temperature. Therefore when waters with a temperature of about 60° F. are collected for bacteriological examination they should be cooled down as quickly as possible. Generally speaking, the higher the temperature of a spring-water, the deeper the source from which it arises. Water issuing from fissures in chalk or other rocks may show variations in temperature, and at least on one occasion this variation in temperature put me on the track of a previously unsuspected source of pollution. An accurately graduated thermometer with the bulb near the bottom of a metallic cup is the most generally useful form of instrument, but in some cases maximum and minimum registering thermometers are necessary for obtaining accurate results. The air temperature at the time of taking the water temperature should always be recorded.

## II.—CHEMICAL EXAMINATION

### A. ACIDITY AND ACTION UPON LEAD

As a matter of routine it is desirable to ascertain the reaction of a water, as, if acid, it will require the addition of an alkali in its subsequent treatment for the estimation of the ammonia. Litmus paper is useless for this purpose with moorland waters, though rain-water caught in the proximity of towns often gives a reaction with it. In the former case the acid is probably organic or carbonic acid, whereas in the latter it is inorganic. Lacmoid is the best indicator for free acid in water, since it is affected by both organic and inorganic acids.

By adding a drop of lacmoid solution to about 10 c.c. of water in a test-tube, the purplish blue of the lacmoid changes to red in the presence of a minute trace of free acid. Moorland waters which give a neutral reaction with this indicator do not dissolve lead to any appreciable extent, whilst a peaty water with an acid reaction will be found to possess plumbo-solvent activity.

For actually estimating the acidity of a water, lacmoid is of little use as an indicator, and preference must be given to phenolphthalein, which allows comparable results to be obtained.

One hundred c.c. of the sample of water, to which a few drops of the indicator have been added, are titrated in a small flask with decinormal solution of sodium carbonate, when the faintest excess of alkali shows itself by a pink coloration of the previously colourless liquid. With care, comparable results may be obtained; but the pink colour, which at first is produced, rapidly fades, and to produce a pink tint which will remain, say, for one minute, more alkali must be added. This may be regarded as the end of the reaction. The amount of acid in the sample of water is represented in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise the acid in the 100 c.c. of water.

In examining the moorland waters of Lancashire and Yorkshire, Houston made many hundreds of estimations of the amount of free acid, and at the same time determined the lead-dissolving power of each sample of water. The following figures taken from Diagram C of his report to the Local Government Board show how the acidity and plumbo-solvency are related :

| Acidity in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the water | Plumbo-solvency. Mlgrms. of lead in 100 c.c. of the water after filtration through lead shot |
|---|---|
| ·18 | ·1 |
| ·2 | ·28 |
| ·27 | ·18 |
| ·3 | ·25 |
| ·4 | ·4 |
| ·45 | ·46 |
| ·5 | ·66 |
| ·52 | ·9 |
| ·68 | 1·34 |
| ·6 | ·92 |
| ·8 | 1·5 |
| ·85 | 1·9 |
| ·9 | 2·4 |
| ·95 | 2·66 |
| 1·1 | 3·2 |
| 1·2 | 4·7 |
| 1·25 | 4·5 |
| 1·3 | 3·4 |
| 1·4 | 2·8 |
| 1·5 | 2·8 |
| 1·58 | 3·0 |
| 1·7 | 5·6 |
| 2·2 | 8·6 |

The following are examples of the manner in which his results are recorded, and show how water from the same stream may vary with the season.

| Sample | Reaction with lacmoid | Acidity in terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ solution | Lead dissolved by 100,000 parts of water in filtering upwards through lead shot at rate of 50 c.c. in three minutes | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| Beck. Dry weather | Neutral . . . | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Beck. Heavy weather | Very acid . . | 1·32 | 2·4 | 3·2 | 3·2 | 3·2 | 3·2 | 3·04 |

As the solvent action of water upon metals is chiefly dependent upon the presence of free carbonic acid, it may be asserted without further proof that an acid water will act upon all metals of which pipes are usually constructed, save copper (?) or tin. The extent of the action of acid waters upon lead may be determined by various methods, of which that devised by Dr. Houston is probably the best, since it allows different waters to be compared with a fair amount of precision. It consists in permitting the water under examination to percolate upwards at a uniform rate through a column of lead shot, collecting the percolate in successive 50 c.c. and estimating the amount of lead therein. A special lead shot is used, as the ordinary article of commerce is an alloy. By continuing the percolation for a period, it can be ascertained whether the action is continuous or whether it tends to diminish. I have recently been examining a moorland water with which it is proposed to supply a large town. At first 100,000 parts of the water dissolved under Dr. Houston's conditions 0·4 part of metal, but this gradually decreased, so that by the third day the amount of lead dissolved was too small to estimate, and on the fourth day lead could not be detected in the water.

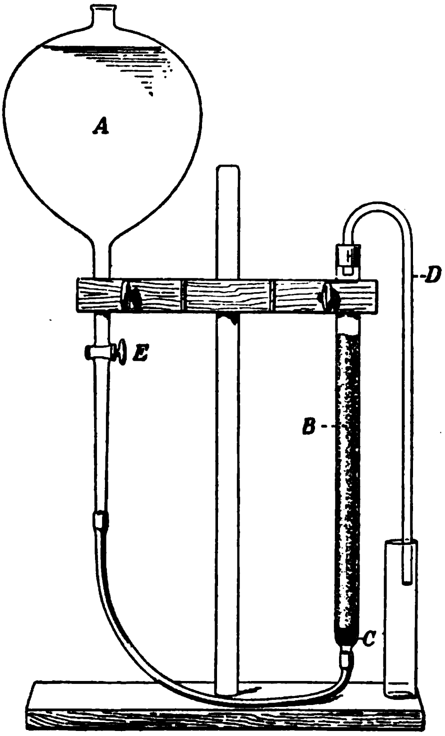

FIG. 7

The apparatus, as fitted up in my laboratory, is shown in Fig. 4. *A* is a bottle containing the water to be examined, *B* a cylindrical tube ½ inch in diameter and about 2 feet long, contracted at the base and containing 50 c.c. of shot resting upon a small plug of muslin or cotton wool, *C*, a glass tube, *D*, conducting the water which has traversed the column of lead shot into the Nessler glasses. The apparatus is used in the following manner :

The large bottle *A* is filled with the water, and the tap *E* turned until the water issues freely. All air must be carefully driven out of the connecting tubes. The cock *E* is then regulated until the water dribbles through at the rate of 50 c.c. in three minutes, after which successive 50 c.c. are collected, and the lead therein estimated as described in the section on lead estimation.

Waters which, though containing no free acid, yet act upon lead, may pass through the above column of shot in the time given without taking up any appreciable quantity of the metal. If, however, the water is allowed to stand a few hours in the apparatus the lead dissolved will be measurable. In such cases it is well to record the amount taken up in a given number of hours.

The shot used in these experiments can be employed repeatedly, provided that after each determination it is taken out of the tube and thoroughly dried by rubbing between the folds of a rough cloth. It is then to be kept in a dry place until again required. It is safer, however, to use fresh shot for each experiment.[1]

Whilst useful for the purpose of comparing waters and for quantitative purposes, my faith in it as a test for deciding whether a water will act upon leaden pipes has been shaken by the discovery that London tap-water when passed through this shot takes up an appreciable amount of lead. As both oxygen and carbonic acid are factors to be considered, I prefer to test a water by placing in it a piece of freshly scraped sheet lead, 2 inches × ½ inch. The piece of lead is put at the bottom of a deep 100 c.c. cylinder containing 100 c.c. of the water and allowed to stand in the dark for twenty-four hours. The water and lead are then examined. Any turbidity or deposit indicates an erosive action, in which case the water must be filtered before testing to ascertain if any lead has entered into solution. Or half may be filtered and tested to ascertain the solvent action and the other half be acidified with acetic acid and the erosive effect determined.

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[1] Special shot prepared for this purpose should be used. It may be obtained from Messrs. Baird and Tatlock, Hatton Garden, London.

If a piece of lead is laid in a Petri dish and covered with the water to be examined, a powerful erosive action may occur, whilst in the deep cylinder no such action can be detected. This action is due to the oxygen of the air, and would not occur in service pipes.

As the result of experience it may be taken that where, in the above experiment, the surface of the lead remains bright, the water has no erosive power; that when the surface becomes tarnished, but the water is unaffected in appearance, the erosive power is so slight as to be negligible, whereas the production of a turbidity or the formation of detached scales indicates an amount of erosive action of a decidedly dangerous character.

Where there is a question as to the action of a water on lead I always estimate the free and combined carbonic acid and the dissolved oxygen. The determination of the temporary hardness will indicate whether the combined carbonic acid exists as calcium or magnesium carbonate or as sodium carbonate. The point, however, is immaterial, as the presence of three or four parts of any of these carbonates in 100,000 parts of the water will prevent any marked solvent action, but in the presence of much free oxygen some erosion may take place.

The methods of determining carbonic acid and oxygen are given in a later section.

The estimation of the former has a bearing also upon the question of softening water.

### B. Hardness or Soap-destroying Power

The hardness or soap-destroying power of a water depends almost entirely upon the amount of calcium and magnesium salts present. Occasionally there is sufficient zinc or iron present in the form of carbonate or sulphate to increase the soap-destroying power, but the presence of free carbonic acid gas and of unusually large quantities of sodium salts is not without effect. The unit of soap-destroying power is one-tenth of that possessed by 100 c.c. of water containing 10 mlgr. of calcium carbonate (or its equivalent of calcium chloride) in solution. The amount of soap destroyed by 1 mlgr. of that salt is not exactly one-tenth of that destroyed by 10 mlgr.; hence Tables have been constructed which pretend to show the amount of calcium carbonate equivalent to the soap solution used. What good purpose is served by such a Table I have never been able to divine. The unit above suggested and generally adopted has a definite meaning and practical use. A water of 8° hardness will waste twice as much soap as one of 4°, and only half as much as one of 16°, &c. Beyond this it means nothing definite, but it gives a rough idea of the amount of calcium and magnesium salts present, and this rough approximation is very often quite sufficient for the purpose of the analyst. If it is not, it is far more satisfactory to determine the amount of these salts by the methods proper for their estimation than to attempt to calculate it from the results of the soap test.

The hardness left after boiling may or may not be entirely due to sulphates and chlorides. The whole of the carbonates is certainly not deposited during the boiling process, both magnesium and calcium carbonate being appreciably soluble in water.

The futility of attempting to determine the amount of the carbonates and sulphates of calcium, and magnesium by the soap test, is exemplified by the following experimental results. The first series were made with artificially prepared solutions to ascertain if the amount of magnesium salt present in a water could be determined by the soap test after removal of the calcium salts by the addition of ammonium oxalate as described in various text-books. The results show that the process is unreliable:

| $CaCO_3$ per 100 c.c. | $MgCO_3$ | Hardness | Hardness after treatment with ammonium oxalate |
|---|---|---|---|
| Mlgr. | Mlgr. | | |
| 5·0 | 2·5 | 9·0 | 1·0 |
| 6·6 | 3·3 | 11·0 | 0·5 |
| 5·0 | 20·0 | 35·0 | 21·0 |

Obviously in these cases the hardness remaining after the precipitation of the calcium as oxalate bears no definite relation to the magnesium salt present. This is further confirmed by the following Table of experimental results showing that the soap-destroying power of 1 mlgr. of magnesium carbonate is not constant.

| Calcium salts as $CaCO_3$ | Magnesium salts as $MgCO_3$ | Total hardness | Calculated hardness corresponding to 1 mlgr. $MgCO_3$ |
|---|---|---|---|
| 5·0 | 5·0 | 12·0 | 1·4 |
| 2·5 | 2·5 | 6·0 | 1·4 |
| 3·25 | 3·25 | 7·5 | 1·3 |
| 5·0 | 2·0 | 9·0 | 2·0 |
| 6·0 | 6·0 | 13·0 | 1·2 |
| 10·0 | 2·5 | 14·0 | 1·6 |
| 10·0 | 5·0 | 15·0 | 1·0 |
| 10·0 | 4·0 | 15·0 | 1·25 |

The end reaction in many of the above cases was difficult to determine.

Similarly the results I have obtained with natural waters, the mineral constituents of which were carefully determined, also show that no definite conclusions as to the salts present in the water can be drawn from a determination of the temporary and total hardness.

I am quite convinced that the hardness of a water cannot be relied upon to indicate anything more than its soap-destroying power, and where a knowledge is desired of the saline constituents it is far better to make a proper quantitative analysis.

The standard 'degree' of hardness unfortunately differs in various countries, but the one I have adopted is that generally employed in France. It can be approximately converted into Clark's (English) degrees by multiplying by 0·7, since Clark's standard degree was 1 grain of $CaCO_3$ in one gallon of water.

**Estimation of the Total Hardness.**—*Reagent.*—Standardised solution of soap.

*Apparatus.*—Burette and stoppered 200 c.c. bottle.

*Process.*—Place 100 c.c. of the water in the bottle and run in the soap solution 1 c.c. at a time until, after vigorous agitation, a lather is formed which persists for five minutes when the bottle is laid on its side. The lather should equal that produced when 1 c.c. of the soap solution is shaken with 100 c.c. of carbonic acid free distilled water. When a lather begins to form, the soap solution can be added in smaller quantities until the requisite permanency is attained. If the water exceeds 16° in hardness, the operation must be stopped and recommenced, using 50 c.c. or 25 c.c. of the original water diluted to 100 c.c. with distilled water. To shorten the process it has been suggested that, at first, a rough experiment should be made, adding the soap solution 5 c.c. at a time. In the second experiment the soap solution is run in more boldly at first, and afterwards in small quantities. The results, however, do not always correspond with those obtained when the soap solution is added more gradually, and this latter method is to be preferred.

As 1 c.c. of soap solution is required to produce a lather in the absence of lime and magnesium salts, the degree of hardness or soap-destroying power is one less than the number of c.c. of soap solution used. Where a diluted water has been used, this, of course, gives the hardness of the dilution, and the hardness of the water will be twice or four times that of the dilution according as 50 or 25 c.c. of the water have been used.

Waters which contain a considerable quantity of magnesium salts may form a distinct curd with the soap. Such waters require copious dilution. Even then the end reaction is difficult to determine, and much experience is required to obtain concordant results. Sometimes a lather will appear to be permanent upon standing, yet if the solution is gently agitated, it disappears, and cannot be reproduced until more soap has been added. In such cases the addition of soap solution must be continued until the frothing is really permanent for five minutes, and is as abundant as it was at first when reshaken.

**Determination of the Permanent and Temporary Hardness.**—For this an Erlenmeyer's flask of 200 c.c. capacity is required. 100 c.c. of the water are placed in the flask and boiled gently for half an hour, distilled water being added from time to time to replace that lost by evaporation.[1] The water is then allowed to cool, passed through a filter paper, made up to the original volume, and the hardness determined in the manner just described. This is the permanent hardness, and the difference between it and the total hardness is the temporary hardness.

As previously stated, the temporary hardness is that removed by boiling, and does not correspond to the whole of the carbonates of calcium and magnesium present, since, after boiling, the water retains a trace of calcium carbonate in solution, and it may contain several milligrams of magnesium carbonate.

Some chemists estimate the temporary hardness from the amount of combined carbonic acid in the water, in the manner described in the section relating to that determination. The equivalent of $CaCO_3$ being ascertained, this is regarded as the temporary hardness, and the difference between this and the total hardness gives the permanent hardness. The results so obtained obviously may differ considerably from those obtained by the more rational process, especially if the water contains magnesium carbonate. When waters contain sodium carbonate, as is very often the case in the deep well-waters of Essex and elsewhere, the process is quite inapplicable. It is best, therefore, to adhere to the soap method, which is universally applicable.

Further reference to this subject will be found in the section relating to the 'Method of determining the amount of lime, &c., required to soften hard waters.'

### C. CHLORINE IN CHLORIDES

The quantity of chlorine existing as chlorides, whether large or small, admits of determination in a very simple manner by the use of a standard solution of silver nitrate, using potassium chromate as an indicator.

**Method of Estimation.** — *Apparatus required.* — Burette graduated in 0·1 c.c. A deep white porcelain dish (200 c.c.), and glass rod.

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[1] If the water is concentrated too highly, calcium sulphate may be deposited and vitiate the results.

*Reagents required.*—Standard solution of silver nitrate, each c.c. of which corresponds to 1 mlgr. of chlorine. Solution of potassium chromate (5 per cent.).

*Process.*—To 100 c.c. of the water in the porcelain dish add 1 c.c. of the solution of potassium chromate. Run in the silver solution carefully, until after stirring a faint, dirty red colour appears and remains permanent. Then from a graduated cylinder or pipette run in more of the water until the clear yellow tint just reappears. The number of milligrams of chlorine in 100 c.c. of water, plus half the further amount added, very approximately corresponds to the number of c.c. of silver nitrate used.

The reaction involved in the above determination consists, in the first place, in the formation of the white insoluble silver chloride, and, when all the chlorine is thus precipitated, the excess of silver is thrown down as red silver chromate. When the silver solution is added to the water containing the potassium chromate, both silver chloride and silver chromate are precipitated; at first the chromate is rapidly decomposed by the chloride remaining in solution, but as the amount of unprecipitated chloride decreases, the decomposition of the silver chromate becomes slower and slower, indicating the approach of the end of the reaction. An excess of silver nitrate must be used to produce the red colour, and this excess varies, within certain limits, with the amount of potassium chromate added. With too small a quantity of chromate, the readings are too high. Why this should be so is difficult to explain. It is quite possible to have a difference of 1 mlgr. in a chlorine determination, due to the improper use of the indicator.

Whilst a deficiency of chromate is to be avoided, an excess is undesirable, as it obscures the delicacy of the end reaction.

The silver solution used is, in the first instance, always in excess of the amount of chlorine present, but when the titration is completed as described, the results are reliable. In the following experiments a solution of pure sodium chloride was used, of such strength that each c.c. corresponded to 1 mlgr. of chlorine. Various quantities of this solution were diluted with distilled water to 200 c.c.; 100 c.c. were titrated; after adding the silver nitrate, more of the dilution was added until the red colour disappeared.

| Chlorine in 100 c.c. | C.c. of silver nitrate solution used | Amount of water in c.c. corresponding thereto | Chlorine found |
|---|---|---|---|
| Mlgr.<br>1·0 | 1·15 | $100 + \frac{20}{2}$ | 1·05 |
| 1·75 | 1·85 | $100 + \frac{12}{2}$ | 1·75 |
| 3·0 | 3·2 | $100 + \frac{6}{2}$ | 3·1 |
| 5·0 | 5·15 | $100 + \frac{4}{2}$ | 5·05 |
| 7·5 | 7·7 | $100 + \frac{3}{5}$ | 7·6 |
| 8·0 | 8·3 | $100 + \frac{2}{2}$ | 8·1 |
| 10·0 | 10·2 | $100 + \frac{4}{2}$ | 10·0 |
| 12·0 | 12·2 | $100 + \frac{3}{2}$ | 12·0 |
| 20·0 | 20·4 | $100 + \frac{3}{2}$ | 20·1 |

With proper care it is rarely necessary to concentrate a water before determining the chlorine; but where very great accuracy is desired, water containing less than 1·0 of chlorine in 100,000 should be evaporated, 500 c.c. or 250 c.c. being reduced to 100. Without evaporation the error need not exceed 0·1 mlgr. of chlorine. With a little experience the change in colour from decided yellow to a pale, dirty red is readily observed. When coloured waters are being examined, such as those containing peaty matters, the delicacy of the reaction is impaired, and concentration of the water is usually necessary. Such waters also have at times an acid reaction, in which case a little sodium bicarbonate must be added before running in the silver nitrate. Sewage-polluted waters, and waters containing traces of sulphuretted hydrogen, can only be titrated after special treatment. Boiling a short time after the addition of a little lime water, the subsequent addition of sufficient sodium bicarbonate to precipitate the excess of lime, and filtration, usually suffice to remove the substances which interfere with the reactions. The titration, of course, must take place after the water, thus treated, has become quite cold.

Colouring matter can generally be removed by boiling the water with a little freshly precipitated aluminium hydrate.

Softened waters, containing an excess of lime, should be rendered faintly acid with dilute sulphuric acid, and the excess neutralised by means of sodium bicarbonate.

## D. Nitrites

The quantity of nitrogen as nitrites found in potable waters rarely amounts to one part in a million, but even this small quantity admits of being easily detected and estimated.

**Detection of Nitrites.**—*Presumptive Test.*—*Reagents required.* Solutions of potassium iodide and of starch. Dilute hydrochloric acid (1 in 6). The reaction depends upon the liberation of iodine from the iodide by the nitrous acid. The oxide of nitrogen produced then acts as a carrier of oxygen from the air, and thus a continuous increase in the amount of iodine set free occurs. The reaction is most delicate when the water is saturated with air ; hence, before adding the reagents, the water should be thoroughly aerated by agitation.

*Process.*—To 50 c.c. of the aerated water add 1 c.c. each of the acid, of the iodide and of the starch solutions. If no blue colour develops in two minutes, nitrites may be considered to be absent. With one part of nitrous nitrogen in one million, a dark blue colour is produced instantly, with one in three millions the colour appears in a few seconds, and with one in ten millions in about thirty seconds.

Ferric salts also liberate iodine from potassium iodide when present in any quantity, but potable water rarely contains sufficient to produce the reaction. Reducing agents, such as sulphuretted hydrogen, ferrous sulphate, &c., may prevent the reaction, but I have not yet met with a water in which both nitrites and reducing agents were present.

A solution of potassium iodide and freshly prepared solution of starch may be used, but the reaction therewith is neither so delicate nor reliable as that with the specially prepared starch solution. I have tried numerous formulæ for starch solutions, and find the only one which can be relied upon is that given in the Appendix.

Time is an important factor in this reaction. Most waters if left to stand long enough exposed to the air, after the addition of the iodide, &c., develop a blue tint. This is especially the case if detectable quantities of manganese salts are present, and to a slighter extent in the presence of traces of ferric salts. It is supposed also that the air of a laboratory often contains sufficient nitrite to produce the reaction. For these reasons the result of the iodide test, when positive, should always be confirmed by the following tests:

If no reaction is obtained in two minutes, nitrites are either entirely absent or present only in such infinitesimal amount as to be negligible. The solution may be allowed to stand for fifteen to thirty minutes or more, and if no colour appears, there cannot be any appreciable amount of ferric or manganic salts present.

For the confirmatory tests now to be described, time also is a factor, the colours produced developing slowly when minute quantities only of nitrites are present, but the results are not affected by the presence of ferric or manganic salts.

The rapidity of the reaction depends, up to a certain point, upon the amount of free acid present, but an excess of acid interferes with the delicacy of the reaction. For this reason the proportion given should always be observed, especially if a quantitative experiment is to be made, and it is always desirable to make a blank experiment to test the distilled water and reagents. If a tint does not appear in ten minutes after adding the reagents to the water, nitrites may be said to be absent. For comparative purposes, no standard which has been prepared for more than half an hour should be used. The exact amount of a nitrite present is very rarely estimated. If the reagents give a reaction within a few seconds, the quantity present may be expressed as a 'large trace.' If it takes a minute or two to show itself, a 'trace' may be said to be present; whereas if the colour only develops towards the end of ten minutes, the amount may be expressed as a 'minute trace.' This really gives all the information desired.

**Naphthylamine Test** (*Ilosvay's*).—*Reagents required.*—Solution of sulphanilic acid. Solution of naphthylamine. Standard solution of sodium nitrite. This is really a modification of Griess's test. It is more delicate, but the results are more affected by variations in the quantities of reagents used.

The examination is conducted as above described, using 2 c.c. of each reagent for 50 c.c. of water. The following results were obtained by experiment :

| Amount of $NO_2$ in mlgr. per litre | Amount of $NO_2$ found | Amount of $NO_2$ in mlgr. per litre | Amount of $NO_2$ found |
|---|---|---|---|
| ·036 | ·037 | ·129 | ·144 |
| ·105 | ·111 | ·24 | ·228 |
| ·207 | ·210 | ·55 | ·56 |

With 0·01 part of N as nitrite in a 100 c.c., this test gives a distinct reaction in two minutes on the average. If more than two minutes elapses before the colour appears, less than this amount must be present.

E. Holl Miller (*The Analyst,* August 1912) describes a test for nitrites which depends upon the formation of paranitrosodimethylamine, by the action of nitrites in a water upon dimethylaniline hydrochloride, and says that it will detect one part of nitrous acid in one million parts of water with ease. I find that the proportion of these reagents affect the result, but applied in the following manner it detects one part in two millions with certainty.

To 50 c.c. of the water add 5 c.c. strong hydrochloric acid and 0·5 c.c. of the solution of dimethylaniline hydrochloride. Allow to stand for fifteen minutes. With one part of $HNO_2$ per million, a yellow tint is perceptible in a minute or two, with one in two millions four or five minutes are required for the colour to develop. With one in four millions I have failed to get any definite reaction, whilst Ilosvay's reagents gave a most decidedly positive result.

The delicacy is sufficient for all practical purposes, but Ilosvay's method is still more delicate. I believe, however, that Miller's reagent will keep better, and if such proves to be the case it will be a decided advantage.

## E. NITRATES

An analysis without a determination of the nitric nitrogen cannot be considered as sufficiently complete for sanitary purposes, although it is not always necessary to make an exact quantitative test. Much uncertainty, however, is caused by the use of such terms as 'trace,' 'minute trace,' &c., and it is desirable, therefore, that the quantity be numerically expressed so that others considering the results can draw their own conclusions.

In no other determination do results differ so widely. On more than one occasion I have had to give an opinion upon a water which had been submitted to various well-known analysts. The other determinations recorded in the analyses have usually been concordant, but the nitric nitrogen has varied enormously. This has not been due to any change in the character of the water, as in some instances the samples were taken at the same time. The difference appears to be due to the methods employed. The only process in which I have perfect confidence is one in which the nitrates are reduced to, and determined as, ammonia, and therefore it is the only one given here.

The hydrogen necessary for the reduction may be obtained by the action of either an acid or an alkali upon the zinc-copper couple. The reaction probably takes place in three stages:

$$\begin{aligned} HNO_3 + H_2 &= H_2O + HNO_2 \\ 2HNO_2 + H_2 &= 2H_2O + 2NO \\ 2NO + 5H_2 &= 2NH_3 + 2H_2O \end{aligned}$$

The test can be applied in various ways, but in order to ascertain the quantity of water to be used, it is advisable to make the following preliminary rough estimation of the amount of nitrates present:

To 50 c.c. of the water in a Nessler cylinder add 1 c.c. of dilute sulphuric acid (1 in 4) and 1 c.c. of the solution of starch, and a minute crystal of potassium iodide. No indication of nitrites being found, add a few milligrams of zinc dust, previously shaken with a little distilled water, and mix thoroughly. When nitrates are present in small quantities a blue colour slowly develops, with larger quantities the colour appears more quickly, and when the nitrates present exceed 1 of nitric nitrogen per 100,000, the colour appears almost instantly. With solutions of potassium nitrate of various strengths, I obtained the following results:

| Nitric nitrogen per 100,000. | | | |
|---|---|---|---|
| ·10 | A distinct blue colour appeared | in | a little under one minute. |
| ·25 | ,, | ,, | about half a minute. |
| ·50 | ,, | ,, | from eight to ten seconds. |
| 1·0 | ,, | ,, | three or four seconds. |

In many cases this rough method gives sufficiently approximate results without further labour. Care should be taken to add just sufficient zinc dust to cause a slight turbidity. If the water contains nitrites, this preliminary test is useless.

When the colour takes some minutes to make its appearance, 100 c.c. of the water are used for determination. When the colour appears almost instantly, 10 c.c. are sufficient. Where the amount of nitrate appears to be very excessive, 5 c.c. may suffice.

(1) **Reduction of the Nitrate to Ammonia in the presence of Acid.**—*Apparatus required.*—Small flask of 50 to 120 c.c. capacity. The usual distilling apparatus.

*Reagents required.*—Granulated zinc. Solution of copper sulphate. Dilute hydrochloric acid. Solution of caustic soda, free from ammonia, or solution of pure sodium carbonate. Nessler solution and standard solution of ammonium chloride.

Place in the small flask sufficient granulated zinc to cover the bottom. Wash the zinc first with sulphuric acid (25 per cent.), then with distilled water. Cover the zinc with distilled water, add about 2 c.c. of saturated solution of copper sulphate, and allow to stand for a few minutes until the zinc is completely covered with a black deposit of copper. Again, wash with several quantities of distilled water, but carefully, so as not to remove the coating of copper. Having, by a preliminary experiment, ascertained how much of the water to be examined should be used, measure this quantity into the flask. Acidulate with one drop of dilute hydrochloric acid (1 in 6), and allow to stand on a hot plate. From time to time add a little more acid, so as to maintain a slight but visible evolution of hydrogen in exceedingly minute bubbles. Keep warm for about an hour, by which time the whole of the nitrates and nitrites will be reduced to ammonia.

Whilst this reduction is taking place, about 250 c.c. of good tap-water to which 5 c.c. of caustic soda solution (10 per cent.), or of saturated solution of sodium carbonate, has been added, are placed in a distillatory flask, and 50 c.c. of water distilled over. This removes any free ammonia from the apparatus and the alkaline water. Now pour the water which has been digested with the copper zinc couple into the flask, using a little pure distilled water for rinsing the zinc, and taking care not to introduce any of the metal into the distillatory apparatus.

Distil over 50 c.c., and nesslerise. If the distillate contains more than 0·05 of ammonia, a second 50 c.c. should be distilled, and the ammonia therein estimated.

From the ammonia thus found the equivalent of nitrogen, or $N_2O_5$ or $NO_3$, is easily calculated.

The apparatus can be used for examining other samples of water which have been treated with copper-zinc, distilled water being added, if necessary, to maintain a volume of about 250 c.c. in the flask prior to commencing the distillation.

The amount of free ammonia in a potable water is usually so small as not to appreciably affect the results, but should a water contain much ammonia, the necessary correction can easily be made, or the free ammonia may be boiled off before introducing the water into the reducing flask.

The following results were obtained with solution of potassium nitrate of known strength. The temperature of the hot plate was about 150° F.

| Nitric nitrogen in mlgrs. per 100 c.c. | | Nitric nitrogen found |
|---|---|---|
| 1·40 | (Digested thirty minutes) | 1·45 |
| 1·40 | (Digested sixty minutes) | 1·40 |
| 1·00 | | ·98 |
| ·56 | | ·56 |
| ·46 | | ·49 |
| ·32 | | ·32 |
| ·20 | | ·198 |
| ·10 | | ·108 |
| ·10 | | ·104 |
| ·05 | | ·055 |

(2) The following method dispenses with distillation and gives very good results:

Proceed exactly as in the first process for the reduction of the nitrates, but instead of distilling, dilute to 49 or 99 c.c. and add a dilute solution of caustic soda or potash drop by drop until zinc hydrate is precipitated and the reaction is faintly alkaline to phenolphthalein. Filter through a washed paper or allow to clear by subsidence; take an aliquot part and nesslerise. The following table shows the results obtainable by this process, using a solution of potassium nitrate in distilled water:

| Nitric N. in 100 c.c. of solution. In mlgrs. | N. found. |
|---|---|
| ·05 | ·055 |
| ·10 | ·108 |
| ·16 | ·14 and ·15 |
| ·20 | ·198 |
| ·40 | ·41 |
| ·80 | ·77 |
| 1·0 | ·98 |
| 1·6 | 1·51 |
| 3·92 | 3·95 |

Certain waters, however, are difficult to compare, becoming on the addition of the Nessler solution slightly turbid, or giving a colour a little different from that obtained with distilled water. In such cases the use of oxalic acid, instead of hydrochloric acid, in the reducing process, possesses an advantage. The process is one of the most rapid, and when a number of waters have to be examined and a very accurate estimation of the nitrates is not necessary, it answers extremely well. By using a copper-zinc couple made with zinc dust, the reduction of the nitrates is effected in a few minutes, but the zinc must first be freed from nitrogen compounds, and this is often difficult. My mode of procedure is as follows: Place about 1 gramme of zinc dust in a stoppered tube and shake with about 10 to 20 c.c. of water. Add drop by drop with continued agitation solution of copper sulphate until the zinc is quite black and settles rapidly. Pour off the supernatant liquid and wash several times with warm distilled water until the clear liquid poured off is no longer appreciably affected by Nessler's solution. The copper-zinc thus prepared can be used for examining two waters in succession.

To the copper-zinc add 5 to 20 c.c. of the water to be examined, the measured quantity taken depending upon the richness in nitrates; warm by immersing the tube in hot water, and shake continuously for about two minutes, by which time the reduction will be complete. Wash a small filter paper thoroughly, filter the supernatant fluid after adding a little caustic soda solution, and wash with distilled water until 50 c.c. are obtained. Nesslerise the filtrate in the usual way.

By this process a number of waters can be examined in an hour. In all these processes the nitrites as well as the nitrates are reduced. The nitrogen in the nitrites must, if necessary, be separately estimated and deducted from the results obtained. The nitrogen in the free ammonia must also be subtracted, if the water used contains sufficient to affect the results and the ammonia has not been removed by evaporation.

The following experimental results show very well the relative value of various processes. An assistant prepared 500 c.c. of water by adding to pure distilled water a little sewage, free from nitrates, some calcium chloride, and magnesium sulphate. To this he added a carefully measured volume of solution of potassium nitrate, each c.c. corresponding to 1 mlgr. nitric nitrogen. The amount of nitrate added was unknown to me. The results obtained by the various processes were as under:

| Process employed | Amount of water used | Nitrogen found per 100 c.c. In mlgrs. |
|---|---|---|
| Indigo . . . . . . . | 10 c.c. | 1·3 |
| „ . . . . . . . | 20 „ | 1·37 |
| Phenolsulphonic acid . . . . | 10 „ | 1·5 |
| „ „ . . . . . . | 5 „ | 1·2 |
| Copper-zinc without distillation . . | 10 „ | 1·23 |
| „ „ . . | 10 „ | 1·13 |
| „ „ . . | 10 „ | 1·16 |
| Copper-zinc with distillation . . | 10 „ | 1·16 |
| „ „ . . | 10 „ | 1·21 |

The results varied from 1·13 to 1·5 per 100,000.

My assistant had added to the ½ litre of water 5·8 c.c. of nitrate solution corresponding to 1·16 N. per 100,000.

Subsequently a sample of water received for analysis was examined ; it contained more nitrates than any so-called potable water I had then met with.

The results were as under :

| Process used | Nitrogen per 100,000 |
|---|---|
| Zinc-copper with distillation | 12·3 |
| ,, without distillation | 11·6 |
| Indigo | 12·0 |
| Phenolsulphonic acid | 10·2 |

I regard the first as being most nearly correct, and the last as the most erroneous.

## F. PHOSPHATES

As has already been stated, phosphates are rarely present in potable waters in appreciable quantities, and their detection and estimation afford no indications of value.

When a water is examined for phosphates, it is usual to simply ascertain their absence or their presence in 'minute traces,' 'traces,' or 'heavy traces.'

The following process is reliable, since it ensures the removal of silica, which otherwise may mislead by giving a reaction which can be mistaken for a 'minute trace' of phosphate. It is due, in my opinion, to the neglect of this precaution that some analysts so often discover traces where I can detect none.

*Reagent required.*—Solution of ammonium molybdate in nitric acid.

*Process.*—Strongly acidulate 100 c.c. of the water with nitric acid and evaporate to dryness in a porcelain capsule. Heat the residue to 120° C. in the hot-air oven for a quarter of an hour, then dissolve in 3 c.c. of distilled water to which 2 or 3 drops of nitric acid have been added. Place 5 c.c. of the ammonium molybdate solution in a test-tube and heat to about 60° C. Pour in the solution of the water residue (unless distinctly turbid it is unnecessary to filter) and set aside in a warm place for about fifteen minutes. The development of a yellow colour but no precipitate indicates a 'minute trace,' a decided turbidity 'a trace,' and a distinct precipitate a 'heavy trace,' of phosphoric acid.

If the total solids in the water have been estimated by the evaporation of 100 c.c. in a platinum dish, the residue may, after solution in a little dilute nitric acid, be transferred to a small porcelain capsule for evaporation to dryness, &c., and be used for this determination. If the evaporation in the presence of acid were conducted in the platinum dish, the chlorine liberated by the action of the nitric acid on the chlorides present would attack the metal, and a trace of platinic chloride be formed, possibly sufficient to impart a faint yellow tint to the solution.

The amount of phosphoric acid present may be approximately estimated by using a standard solution of sodium phosphate, of which 1 c.c. = 0·1 mlgr. of the anion $PO_4$, and diluting various amounts of this with water to 3 c.c., adding 2 or 3 drops of strong nitric acid, and proceeding as already described. These standards can then be compared with the results obtained with the water under examination.

✓

## G. AMMONIA

The so-called free ammonia found in nearly all waters exists probably in combination with some acid, but upon boiling, any carbonate present causes its expulsion as ammonium carbonate. In the absence of carbonates, the addition of a little recently ignited sodium carbonate to the water is necessary before distilling. Unless, therefore, a water is known to contain carbonates, it should be tested by the addition of a drop of lacmoid solution to about 20 c.c.; if acid, the water will acquire a faint red tint; if carbonates are present the tint will be decidedly blue.

*Reagents required.*—An abundance of ammonia-free distilled water. Standard solution of ammonium chloride, 1 c.c. = 0·01 mlgr. of ammonia. Nessler solution.

*Apparatus.*—Retort or boiling flask and condenser. 50 c.c. and 100 c.c. Nessler cylinders. Burette or pipettes for the standard ammonia solution. Pipette holding about 2 c.c. for measuring the Nessler solution. 500 c.c. measuring flask.

The following illustration (fig. 5) is taken from the apparatus used in my laboratory.

For measuring the Nessler solution, and mixing it with the water, I use a 2 c.c. pipette which has been cut so that it admits and discharges very freely. When the bulb is inserted in the Nessler solution, it immediately fills, and by closing the upper end with the finger the requisite quantity can be readily removed and discharged. This avoids any disturbance of the deposit which usually forms at the bottom of the bottle containing the reagent.

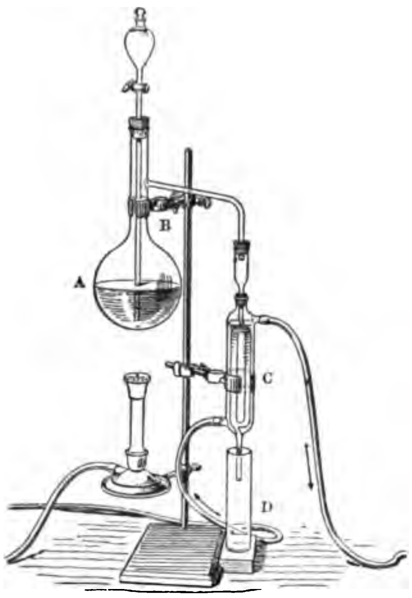

FIG. 8.—A, flask with tubulure, holding about 600 c.c. and supported by a clamp, B; C, glass vertical condenser with support; D, Nessler cylinder.

*Process.*—Introduce into the flask 500 c.c. of the water to be examined, and distil. The distillation at first should be slow and kept as regular as possible. If there is any doubt about the apparatus being ammonia-free, or if any ammonia has been recently used in the laboratory, it is best to put a little good tap-water into the flask and distil until the distillate, when tested with Nessler reagent, proves to be quite free from ammonia. The flask may be cleansed by rinsing first with a little strong hydrochloric acid and afterwards with successive quantities of good tap-water until every trace of acid has been removed.

The distillate is collected in cylinders marked at 50 c.c. When the first 50 has come over, about 2 c.c. of the Nessler solution are added to it and well mixed. Into a second similar cylinder a measured quantity of the ammonium chloride solution is diluted to 50 c.c. with ammonia-free water, and to the mixture 2 c.c. of the Nessler solution are added. If the two liquids after standing two or three minutes have approximately the same tint, the standard will serve for the estimation. If there is a marked difference, fresh standards must be made, weaker or stronger as the case may be, until one of approximately equal strength is obtained. The two cylinders used must be of the same diameter, so that the columns of liquids are exactly the same height. If one solution is a little darker than another, this is transferred to a graduated cylinder, and then poured back slowly until the tint of the column exactly corresponds with that of the paler. The strength of either solution can then be readily estimated. For example, the distillate (50 c.c.), after addition of Nessler solution, acquires a colour a little darker than that of a standard containing 5 c.c. of ammonium chloride solution (0·05 mlgr. $NH_3$). Transferred to the measuring cylinder, the volume of the liquid is 52 c.c., and 48 c.c. poured back gives a column similar in depth of colour to the standard.

The ammonia in the distillate $\frac{52}{48} \times 0{\cdot}05 = 0{\cdot}054$ mlgr.

Assuming, on the other hand, that the standard solution is a little darker, and that 48 c.c. = the 52 c.c. of distillate and Nessler solution, the ammonia in the distillate would then be $\frac{48}{52} \times 0{\cdot}05 = 0{\cdot}046$ mlgr.

If a distillate contains much more than 0·10 ammonia in the 50 c.c., it cannot be very accurately nesslerised. If great accuracy is desired, it is better to start afresh and use an aliquot part of the 50 c.c. distillate diluted. To avoid this loss of time, it is well to nesslerise a little of the water without distillation. If the addition of the Nessler solution gives a visible yellow tint, it is evident that the concentrated distillate will require dilution to permit of the ammonia being estimated.

If the first 50 c.c. contains not more than 0·02 or 0·03 of ammonia, the second 50 c.c. is usually ammonia-free; but a second and a third 50 c.c. should be collected and examined. The residue left in the flask can be used for estimating the amount of ammonia produced by the action of a strongly alkaline solution of potassium permanganate upon the organic matter in solution, as described in the next section. This ammonia is usually spoken of as 'albuminoid' or 'organic' ammonia.

On the Continent this latter process is but rarely used, and the free ammonia is generally estimated without resorting to distillation by the following process:

*Requisites.*—250 c.c. stoppered flask, and a solution of sodium hydrate and carbonate (containing about 5 per cent. of each), previously boiled, so as to free it from all traces of ammonia. About 200 c.c. of the water are introduced into the flask, and 5 c.c. of the alkaline solution added. The stopper is then inserted, the flask well shaken, and set aside for about twelve hours. At the end of this time the calcium and magnesium salts are deposited, and portions of the clear liquid can be drawn off by means of a pipette, and the ammonia directly estimated by the addition of Nessler solution in the manner above described.

Many waters can be nesslerised without even this preliminary treatment, but the results are not nearly so accurate as when the ammonia is concentrated by distillation. For some purposes, however, the information obtained may be sufficient.

The amount of ammonia in 500 c.c. having been determined by distillation, the amount present in parts per 100,000 or in parts per million is easily calculated.

Some waters yield a distillate having a decided odour, and giving with the Nessler solution a colour slightly different from that yielded by ammonia. These waters probably contain traces of compound ammonias, and are always of a suspicious character.

### H. Albuminoid or Organic Ammonia

The process adopted for obtaining this rough index of the amount of organic matter in solution is always conducted with the water from which the free ammonia has been driven off by distillation, and the ammonia produced by the action of the permanganate is estimated in the distillate in the manner just described. The apparatus required is that which is used for the free-ammonia determination, and the only additional reagent is a strong alkaline solution of potassium permanganate. After removing the 150 c.c. of the water by distillation in estimating the free ammonia, there remain in the flask 350 c.c. of the concentrated water. A further 100 c.c. is distilled off, and to the residue is added, best by aid of a suitable stoppered funnel, 50 c.c. of the alkaline solution, and the distillation is slowly resumed. Three successive 50 c.c. are drawn over, and the ammonia contained therein estimated. This represents the amount yielded by the 500 c.c. of the water.

The water, after the addition of the alkali, often boils intermittently, and is then said to 'bump.' This may easily lead to a loss of ammonia, or to the fracture of the flask. The 'bumping' may generally be avoided by introducing into the flask a few small pieces of recently ignited pumice or pipe stem, or by adding short pieces of capillary glass tubing, each of which has been sealed at *one end*.

There are numerous modifications of these processes for determining the free and organic ammonia, all devised with one view, that of increasing the accuracy of the results. These refinements take away from the simplicity of the process without any compensating advantage. The minute errors avoided are utterly inconsequential in interpreting the results, as has been demonstrated in the section treating of the interpretation of analyses.

A stoppered retort and Liebig's condenser can be used, but the arrangement is cumbersome. The apparatus (figured) takes up little space, and is very convenient. Care should be taken to employ rubber stoppers and tubing which have been used for no other purpose, and to be certain that the whole apparatus is ammonia-free. If not used for a few days, it is always advisable to distil a little clean water until the distillate is ammonia-free, and then rinse out the flask with pure distilled water before introducing the water to be examined.

## I. Estimation of the Organic Nitrogen

For reasons previously given some few chemists prefer to estimate the total nitrogen in the organic matter present in a water. The determination, if properly made, is tedious and troublesome, and the results are of no greater value than those obtained by the simpler processes for the estimation of the organic and albuminoid ammonia. Very few experiments convinced me of this fact, and I have never adopted it as a routine process. The safety of a water does not depend upon its containing a little less or a little more nitrogenous matter; it may contain relatively large amounts and yet be perfectly wholesome, and it may contain very small amounts and yet be dangerously polluted. Neither the albuminoid ammonia nor the total nitrogen determinations can be depended upon to detect minute quantities of sewage in water, and when more information is wanted than can be obtained by the ordinary method of chemical analysis, it should be obtained by a bacteriological examination.

The process requires the use of special flasks, very pure concentrated sulphuric acid, and pure sodium hydroxide. A blank experiment should be made with the reagents used, and the ammonia obtained deducted from that found in the final distillate from the water examined.

Five hundred c.c. of the water are introduced into the ordinary distillatory apparatus, and the distillation continued until only about 100 c.c. remain. This is transferred to a Kjeldahl flask, and 10 c.c. of the pure concentrated sulphuric acid added. Evaporation is continued on a sand bath in a fume chamber until acid fumes are given off, and the liquid has acquired a pale yellow colour. A few milligrams of powdered potassium permanganate are then added, and the heating continued until the liquid is of a decided green colour. It is then allowed to cool, and, after the addition of 200 c.c. of ammonia-free distilled water, it is transferred to the distillation flask, into which 100 c.c. of caustic soda solution (No. 45) are poured. The ammonia formed by the action of the strong acid on the organic matter is then distilled off, and nesslerised in the usual manner. Or the Nessler cylinder, into which the water is to be distilled, may contain a little distilled water, slightly acidified with hydrochloric acid, and the end of the condensation tube made to terminate below the surface of the acidulated water. By this method, and by distilling the first 50 c.c. very slowly, any loss of ammonia can be avoided. When 200 c.c. have distilled over, 50 c.c. of the distillate, rendered alkaline if the latter method of collection has been used, may be nesslerised. The ammonia found in the 50 c.c., multiplied by 8, gives the amount of ammonia obtainable from a litre of the water, and to convert this into nitrogen it is only necessary to multiply by $\frac{14}{17}$. The amount found in the blank experiment being deducted, the nitrogen derived from the organic matter in the water is known.

*Example.*—A water which yielded 0·008 part per 100,000 of organic ammonia was submitted to Kjeldahl's process. The blank experiment showed that the ammonia yielded by the chemicals was 0·035 mlgr.

Five hundred c.c. of water were taken, and the ammonia found in 50 c.c. of the distillate of 200 c.c. was 0·035 mlgr., or in the whole 200 c.c., 0·140 mlgr. From this had to be deducted 0·035 mlgr. found in the chemicals, leaving 0·105 mlgr. as being derived from the 500 c.c. of water. This corresponds to 0·087 mlgr. of nitrogen. The organic nitrogen, therefore, was 0·174 mlgr. per litre, or 0·0174 part per 100,000.

The method is, undoubtedly, much more scientific than that of determining the organic ammonia, and notwithstanding its tedious character, the necessity for using a fume cupboard, &c., it would long ago have been generally adopted had it possessed any advantage over the less scientific but simpler process.

The nitrogen in nitrates and nitrites is not included in this determination, nor does their presence in such quantities as are ordinarily found in potable waters appear to affect the results. Many modifications have been suggested, all introducing additional possible sources of error and complicating the process ; it is not necessary, therefore, to make any further reference to them.

## J. Oxygen Absorbed

All waters when strongly acidulated with sulphuric acid and digested with a little permanganate of potash absorb from this salt more or less oxygen, the amount of which can be determined if the amount of available oxygen in the permanganate added is known and the amount left after the action of the water is determined. The difference gives the oxygen absorbed by the constituents of the water. Some very pure waters absorb very little indeed, less than 0·1 mlgr. per litre, while others containing organic matter in solution absorb many times this amount. Although, strictly speaking, an index neither to the quantity nor to the quality of the organic matter, yet, as the amount absorbed varies in different waters, being usually very small in pure waters and comparatively large in impure waters, the determination is not without value. Certain inorganic substances occasionally found in waters, such as nitrites, ferrous salts, and sulphides, also reduce permanganates. These act on the permanganate with rapidity, whilst the organic matter acts very slowly. When any of these substances are present, two determinations are generally made, one to ascertain the amount of oxygen absorbed by the inorganic matter, and the other to estimate the total absorbed oxygen, and the difference is taken as being the amount consumed by the organic matter.

The total oxygen consumed varies greatly in the same water, the chief factors being time and temperature; but the degree of acidity and the intensity of the light are not unimportant. For results to be comparable, therefore, they must have been obtained by identical processes. Some chemists, and these are in the majority, maintain the water at 80° F. for three hours, whilst others prolong the time to four hours. Some digest at the room temperature, considering the temperature of the laboratory to be sufficiently constant, whilst others again prefer a temperature of 122° F. or 212° F., and reduce the time to from fifteen minutes to one hour. Continental chemists make very little use of the process, and some prefer to use an alkaline rather than an acid solution. I have tried all the processes in use and many others which have been suggested, but have not found that any yield more reliable results than the following slight modification of the process recommended by the late Dr. Tidy, which was again a modification of Forchammer's method. My method differs only from Tidy's in that I prefer working at 98° F. instead of 80° F., because that is the temperature of the ordinary warm incubator now found in every properly equipped laboratory. In the incubator also the absence of light is secured, so that the conditions are easily kept uniform.

*Apparatus and Reagents required.*—Standard solution of potassium permanganate, 1 c.c. = 0·1 mlgr. available oxygen. Solution of sodium thiosulphate, 1·0 gramme to the litre. Solutions of potassium iodide and of starch. Solution of sulphuric acid 25 per cent. Stoppered bottles or flasks holding about 400 c.c. Burettes, pipettes, &c. Two hundred and fifty c.c. of the water to be examined heated to 98° F. are measured into one of the bottles or flasks, which should have been previously cleaned with acid, &c. To this are added 10 c.c. of the solution of potassium permanganate and 10 c.c. of the sulphuric acid, and, the stopper being inserted, the bottle is placed in an incubator kept at about 98° F. Let it remain there for three hours, examining it from time to time to see that a decided pink colour remains. If the colour tends to disappear, add a second 10 c.c. of permanganate solution, as this should always be present in marked excess. Whilst this is 'incubating,' place 250 c.c. of recently distilled water in a second flask, add 10 c.c. of the acid, 10 c.c. of the permanganate, and 1 c.c. of 5 per cent. solution of potassium iodide and titrate with the thiosulphate solution, using starch as an indicator. The amount of solution used corresponds to 1 mlgr. of available oxygen, or to 10 c.c. of the permanganate solution. The thiosulphate solution not keeping well, this standardisation should be repeated with every fresh batch of waters or every few days. On no account should the thiosulphate solution be made with a water containing nitrates, for, if so, nitrites may be formed and vitiate the experiment.

The water, after the lapse of three hours, is removed from the incubator, and quickly reduced to the room temperature by immersing the bottle in cold water. The iodide is then added, and the excess of permanganate estimated. In this determination it is most important to cool the water, as the amount of thiosulphate required to destroy the blue colour of the iodide of starch is markedly affected by the temperature. This is another of the causes, not generally recognised, of the differences in the amount of oxygen absorbed, found by different analysts when examining the same water.

If it is desired to estimate the oxygen absorbed by the inorganic matter, the water may be warmed to 98° F., and the acid and permanganate added as before. The mixture is allowed to stand for five minutes, then cooled rapidly, and the unreduced permanganate estimated. In examining potable waters this determination is rarely required.

The following are examples of results obtained with various waters:

1. A deep well-water of known purity.

The thiosulphate solution on standardising required 28·7 c.c. to decolourise the iodine liberated by 10 c.c. of the permanganate solution.

The water, after the addition of acid and permanganate and being maintained for three hours at 98° F., required 27·6 c.c. of thiosulphate solution.

$$28{\cdot}7 : 1 :: (28{\cdot}7 - 27{\cdot}6) : x \text{ oxygen absorbed by the 250 c.c. of water.}$$

$$x = 0{\cdot}0383 \text{ mlgr.}$$

corresponding to 0·153 mlgr. per litre, or 0·0153 part per 100,000.

2. A peaty moorland water, free from suspicion of manurial or sewage contamination.

Thiosulphate solution 30·1 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 16·4 c.c.

$$30{\cdot}1 : 1 :: (30{\cdot}1 - 16{\cdot}4) : x = 0{\cdot}455 \text{ mlgr.,}$$

or 1·82 parts per million, or 0·182 part per 100,000.

3. A shallow well-water undoubtedly contaminated by leakage from house drain.

Thiosulphate solution 29·0 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 18·2.

$$29{\cdot}0 : 1 :: (29{\cdot}0 - 18{\cdot}2) : x = 0{\cdot}3724,$$

or 1·489 parts per million, or 0·149 part per 100,000.

The general formula for the calculation is—

$$\frac{a - b}{a} \times 4 = \text{parts per million},$$

where $a$ = the number of c.c. of thiosulphate solution equivalent to 10 c.c. of the permanganate solution, and $b$ = the number of c.c. of the thiosulphate solution used at the end of the incubation. If 20 c.c. or 30 c.c. of the permanganate solution have been added, then the numerator becomes $2a - b$ or $3a - b$.

Results obtained under one set of circumstances cannot be compared with those obtained under others. The oxygen absorbed by the same waters varies, as has been stated, and the effect of certain of the factors influencing the results are shown in the following experimental results :

*Example* 1.—TAP-WATER CONTAINING 0·1 PER CENT. OF SEWAGE EFFLUENT. OXYGEN ABSORBED IN PARTS PER 100,000

| | |
|---|---|
| Digestion for four hours at room temperature (about 65° F.) | ·0262 |
| ,, ,, ,, in incubator (about 98° F.) . . | ·0303 |
| Kept for one hour at 212° F. . . . . . . . . | ·1520 |

*Example* 2.—TAP-WATER

| | |
|---|---|
| At room temperature . . . . . . . . . | ·0151 |
| At 98° F. . . . . . . . . . . . . | ·0262 |
| At 212° F. . . . . . . . . . . . . | ·0840 |

These and similar results show that there is no approximately constant factor for converting results obtained in one way into those obtained in another.

*Example* 3

| | Polluted Well-Water | Peaty Water | Tap-Water, 5 per cent. of sewage effluent |
|---|---|---|---|
| Four hours at 98° F. . | ·364 | ·163 | ·061 |
| Boiled for fifteen minutes | ·740 | ·300 | ·132 |

The effect of exposure to sunlight on the amount of oxygen absorbed varies considerably with different waters. With very good waters absorbing little oxygen the difference produced is slight, but in the presence of organic matter the result of exposure is to increase the amount of oxygen absorbed. A water to which permanganate has been added, and which remains pink and bright in the dark, often becomes brown and turbid if exposed to bright sunlight. The results obtained by different exposures are shown in the following table. All the experiments were made at as nearly as possible the same temperature, the bottle in the dark being in black paper or in a cardboard box, side by side with the exposed bottle.

OXYGEN ABSORBED IN THREE HOURS IN PARTS PER 100,000

| | In incubator at 98° | In dark at room temperature | Exposed at room temperature to bright light |
|---|---|---|---|
| A well-water containing vegetable matter | — | ·058 | ·186 |
| Chalk spring | ·116 | ·072 | ·165 |
| An impure water | — | ·179 | ·233 |
| New River Co. water | — | ·0107 | ·0131 |
| New River Co. water | — | ·0132 | ·0166 |

Many waters absorb more oxygen from a strongly alkaline solution of permanganate than from an acid solution, and I at one time thought that this was especially the case when the waters were sewage-polluted. A long series of experiments, however, demonstrated that this difference could not be depended upon to distinguish between 'recent' and 'previous' sewage pollution, or between organic matter of vegetable and of animal origin.

In the following experiments the oxygen absorbed in the acid solution was determined in the way above described, after standing four hours at 80° F., whilst the alkaline solutions were made by adding 10 c.c. of 20 per cent. solution of sodium hydrate in place of the acid. After standing four hours at 80° F., they were rendered acid by the addition of dilute sulphuric acid, and the titration with thiosulphate completed in the usual way.

IN PARTS PER 100,000

| | Oxygen, absorbed from acid permanganate | Oxygen, absorbed from alkaline permanganate |
|---|---|---|
| Dilute infusion of deal shavings | 1·71 | 1·66 |
| ,, ,, ,, | ·528 | ·532 |
| Infusion of decayed leaves | ·084 | ·099 |
| ,, ,, | ·122 | ·132 |
| ,, ,, | ·160 | ·144 |
| ,, ,, | ·128 | ·124 |
| Water plus urine | ·385 | ·180 |
| ,, ,, | ·224 | ·212 |
| ,, ,, | ·328 | ·208 |
| ,, ,, | ·332 | ·296 |
| ,, ,, | ·256 | ·164 |
| Sewage-polluted river-water | ·540 | ·700 |
| ,, ,, | 1·360 | 1·510 |
| Tap-water | ·058 | ·053 |
| Tap-water + sewage effluent | ·288 | ·362 |

Similar experiments made with alkaline solutions of different strengths, and with alkaline carbonates instead of hydrates, all tended to prove that the results were of no value for indicating the nature of the organic matter, and that for purposes of comparison the processes possessed no advantage over the one usually employed, and were more troublesome to perform.

When many samples have to be compared, and time is an important factor, the oxygen absorbed by the water at 212° F. in fifteen minutes may be determined, but such occasions must be exceptional.

The reactions which take place in these various processes may be represented by the following equations:

$$4KMnO_4 + 6H_2SO_4 = 2K_2SO_4 + 4MnSO_4 + 6H_2O + 5O_2$$

$$O_2 + 4HI = 2H_2O + 2I_2$$

$$I_2 + 2Na_2S_2O_3 = Na_2S_4O_6 + 2NaI$$

## K. DETECTION AND ESTIMATION OF IRON

Water containing even a small trace of iron usually becomes opalescent upon exposure to air. This is apparently due to the absorption of oxygen and the formation of an insoluble oxycarbonate from the soluble bicarbonate. If it is desired merely to ascertain the presence or absence of a minute trace of iron salt, the method I adopt is as follows :

To 50 c.c. of the water, previously agitated, add 1 c.c. of dilute sulphuric acid (1 in 4) and drop by drop a solution of potassium permanganate (1 c.c. = 0·1 mlgr. O), until the faintest possible red tinge is discernible and persists for some minutes. The application of heat may be necessary, if the water is turbid, to ensure the solution of the iron and its conversion to the ferric state; filtration through paper removes the last trace of permanganate. Now add 1 c.c. of the solution of potassium ferrocyanide, when a blue tint will be produced if more than one part of iron is present in 10 million parts of water, corresponding to 0·01 part per 100,000. The amount of iron present may be estimated by making a solution which gives with the ferrocyanide a colour of equal intensity. For this purpose the standard solution of iron, each c.c. of which corresponds to 0·1 mlgr. of Fe, may be used. This is diluted with varying quantities of distilled water, and to each 50 c.c. 1 c.c. of dilute sulphuric acid and 1 c.c. of the ferrocyanide solution are added. If necessary the process must be repeated until the standard solution and the water have the same tint. If the difference is but slight, the exact amount may be determined by varying the lengths of the columns and making the necessary calculation. If the water gives a dark blue colour with the ferrocyanide, it should be diluted with a definite quantity of water until the tint produced admits of being easily compared.

I have found this the simplest and most accurate method for determining the amount of iron present. The following table shows that the results are sufficiently accurate for all practical purposes.

| Amount of iron in 100 c.c. | Amount found |
|---|---|
| ·032 mlgr. | ·032 mlgr. |
| ·041 „ | ·0375 „ |
| ·041 „ | ·040 „ |
| ·090 „ | ·080 „ |
| ·200 „ | ·200 „ |

If the water has been heated to effect solution, it must be allowed to become quite cold before the quantitative tests are applied.

A little bromine water may be used instead of the permanganate for the oxidation of the iron and the excess removed by boiling, but this possesses no advantage over the process just described. Nitric acid is also often used for effecting oxidation before adding the ferrocyanide, or potassium sulphocyanide may then be used for detecting and estimating the amount of iron present, but I have not found it as reliable in quantitative estimations as could be desired.

The ferrocyanide solution should not have been kept any length of time. A freshly prepared solution is to be preferred.

If exceedingly minute traces of iron are to be estimated, the water may be evaporated down to a fractional part before applying the reagents.

In some cases both the iron in solution and that in suspension require determination. For this purpose the metal is estimated in an unfiltered and a filtered sample and the difference gives the amount in suspension. It should be remembered, however, that many waters submitted for analysis, and which, when received, are quite turbid, were perfectly clear and bright when taken from their sources. The oxysalts deposit after the water comes in contact with air, hence the amount of iron in suspension will depend upon the extent of the exposure. When such a water is submitted to a softening process, the iron is removed with the carbonate of lime.

### L. Detection and Estimation of Manganese

The manganese present in a water may be either in suspension or solution, and may exist in different states of oxidation, as manganous or manganic salts or oxides. The manganic salts liberate iodine from potassium iodide in acid solution even when there is only one part of manganese in 10 million parts of water. If starch be present a blue colour appears, and remains fairly constant, whilst the colour produced by nitrites continuously deepens.

If the Griess-Ilosvay test shows the absence of nitrites and only traces of iron are present the following 'presumptive' test for the presence of manganese may be applied.

To about 50 c.c. of the water add sufficient solution of pure sodium hydrate to render it distinctly alkaline, shake occasionally for about an hour. Then acidify with dilute hydrochloric acid and add a little potassium iodide and starch solution. If a blue colour develops manganese is probably present. With 1 part in 10 million of water the colour is just perceptible, with 1 in 2 or 4 million the test is distinct almost as soon as the acid is added. The depth of the colour produced gives a rough idea of the amount present, and the information is useful for the following 'confirmatory' test. If the water contains an appreciable amount of organic matter, the delicacy of the 'presumptive' test is impaired. Take a quantity of the water containing from 0·5 to 1 mlgr. of manganese, not more, acidulate with pure sulphuric acid, evaporate to dryness and gently ignite. This removes all chlorine and organic matter which might afterwards interfere with the reaction. Dilute 5 c.c. of strong sulphuric acid, and 5 c.c. of strong nitric acid (free from other oxides of nitrogen) with 20 c.c. of distilled water, and by aid of this mixture transfer the water residue to a small flask. Add about 2 grammes of lead peroxide and simmer gently for a few minutes, dilute with a little boiling water and then allow the solution to stand until clear (or filter through washed asbestos in a Gooch crucible). The manganese present will exist as permanganic acid and the amount can be estimated by adding standard permanganate solution to a mixture of sulphuric and nitric acids and water until the colours correspond.

There are many modifications of this process, but they appear to possess no advantages. By using a dilute solution of ammonium oxalate of known strength the manganese may be determined volumetrically. When estimating the manganese in a series of samples of water, and of sedimentary deposits, I concluded that the process as described above gave the most reliable results.

If a water residue is mixed with a little sodium carbonate and potassium nitrate and heated to fusion, the presence of manganese will be shown by the production of a green colour. This reaction, however, does not appear to be as delicate as the potassium iodide test: ‘presumptive’ test given above. It is useful, however, as a ‘confirmatory’ test if there is an appreciable amount of manganese present.

## M. Detection and Estimation of Zinc

The test applied for the detection of iron will almost certainly have given indications of the presence of zinc, if any compound of this metal be present, by the appearance of an opalescence due to the formation of the very insoluble zinc ferrocyanide. The test can be repeated, omitting the addition of the potassium permanganate. With 0·05 mlgr. of zinc in 100 c.c. a decided opalescence will appear in a few minutes, with 0·1 mlgr. the turbidity is obvious in about one minute, whilst with 1 mlgr. the turbidity appears in a few seconds. The amount of zinc present can be estimated by adding successively to 50 c.c. of the water 1 c.c. of dilute sulphuric acid and 1 c.c. of solution of potassium ferrocyanide. The opalescence produced is then imitated by adding the same quantities of reagents to water to which known quantities of solution of zinc sulphate (1 c.c. = 0·1 mlgr. Zn) have been added. The turbidity, save in excessively dilute solutions, reaches its maximum in about five minutes. Slight variations in the quantity of acid or ferrocyanide solution do not appear to affect the results, but the nature of the acid and the quantity are not without effect if a marked excess is employed, so that the experiment should be conducted as described. The reaction is very delicate, and will with certainty detect 1 part of zinc in 2,000,000 of water even in the presence of a trace of iron. When the amount present exceeds 1 mlgr. in 100 c.c., it is advisable to dilute the water before estimating the zinc. The following table shows that the results obtained are sufficiently reliable:

| Zinc in 100 c.c. | Zinc estimated | Zinc in 100 c.c. | Zinc estimated |
|---|---|---|---|
| ·0875 mlgr. | ·100 | ·50 mlgr. | ·50 |
| ·10 ,, | ·075 | ·56 ,, | ·50 |
| ·21 ,, | ·200 | ·70 ,, | ·75 |
| ·25 ,, | ·280 | | |

The presence of any appreciable quantity of zinc is also indicated when the water is being boiled or evaporated. A peculiar opalescence is usually observed before ebullition commences, and when the water is being evaporated a characteristic film appears on its surface.

## N. Detection and Estimation of Copper

This metal also is detected by the ferrocyanide test. The copper ferrocyanide produced imparts a reddish-brown tint to the water, and the amount of the metal present can be approximately estimated by comparing the tint produced with that formed in solutions of known strength. Using 50 c.c. of water in an ordinary Nessler cylinder, this test will detect 0·025 mlgr. of copper in 100 c.c.

The presence of iron interferes with this reaction, but that of lead does not. If iron be present and lead absent, the copper may be estimated by the addition of $H_2S$ or an alkaline sulphide to an acid solution in the manner described under 'Lead,' using a standard solution of a copper salt in place of that of lead.

Copper is very rarely present, but I have detected it in an acid moorland water which had passed through a copper cylinder.

Copper sulphide is soluble in potassium cyanide, hence if $H_2S$ gives a coloration with the acidulated water, but no coloration if KCy has previously been added, the presence of this metal is confirmed.

## O. Detection and Estimation of Lead

Lead may be tested for in water in various ways.

1. By acidulating with acetic acid and adding a few drops of solution of potassium chromate.

2. By acidulating with hydrochloric acid and treating with sulphuretted hydrogen.

3. By adding a drop of calcium (or ammonium) sulphide solution, and acidulating with hydrochloric acid.

The first test cannot always be relied upon. Under some circumstances it will give a turbidity with a water containing 0·03 mlgr. of lead per 100 c.c., whilst under others it will give no indications of the presence of 0·1 mlgr. As a confirmatory test, using a concentrated water, it is, however, of value. It is not affected by the presence of copper.

The sulphuretted hydrogen test is more delicate than the chromate test, but it does not distinguish between lead and copper, and as other metals give a discoloration with $H_2S$ in an acid solution, the result, if positive, should always be confirmed by evaporating a portion of the water, and submitting it to the chromate test.

The third test is the one I generally employ, as it is as delicate as the $H_2S$ test, and does not necessitate the use of any offensive reagent. To 100 c.c. of the water in a Nessler cylinder, add a droplet of a freshly prepared solution of calcium sulphide, and faintly acidulate with hydrochloric acid. Colourless ammonium sulphide, or sulphuretted hydrogen gas may be used instead of the calcium sulphide. The result is in all cases the same, lead sulphide being formed and giving a colour varying from the faintest brown to a black brown, according to the amount of lead present.

If 0·05 mlgr. of lead be present in 100 c.c. of the water, a very faint red-brown tint develops, easily discernible upon comparing it with that produced when the reagents are added to a pure water, the cylinders being placed on a white tile.

If either sulphide is used, upon standing sufficiently long a little sulphur is deposited as a layer on the bottom of the cylinder. In the absence of any coloured sulphide this layer is quite white, whereas if lead or any metal forming a coloured sulphide is present, the sulphur is tinted.

Assuming a coloured precipitate to be produced, the chromate test should be applied, after evaporation if only a minute trace is indicated. The production of an opalescence confirms the presence of lead.

The sulphide test is easily rendered quantitative by using a standard solution of a lead salt (1 c.c. = 0·1 mlgr. Pb), and adding varying quantities to 100 c.c. of water until a solution is produced giving the same depth of tint when treated as that given by the water under examination.

A solution of calcium sulphide possesses certain advantages over ammonium sulphide and is equally delicate as a test. Using this reagent, the following tests were made to prove its suitability for quantitative work :

| Amount of lead in 100 c.c. of water | Amount found |
|---|---|
| ·40 mlgr. | ·40 mlgr. |
| ·28 ,, | ·26 ,, |
| ·20 ,, | ·20 ,, |
| ·14 ,, | ·12 ,, |
| ·12 ,, | ·10 ,, |
| ·08 ,, | ·08 ,, |
| ·08 ,, | ·09 ,, |
| ·02 ,, | ·02 ,, |

Waters containing an excessive amount of lead may require dilution, and those containing exceedingly minute amounts require concentration before adding the sulphide for the quantitative determination. The best strength for purposes of comparison is about 0·2 to 0·5 mlgr. of Pb in 100 c.c. of water.

## P. DETECTION AND ESTIMATION OF ARSENIC

I have only once had occasion to test for arsenic in a potable water. The water was derived from a well in a garden adjoining a path which was very free from weeds. I casually heard that a weed killer had been used, and I suspected that this was an alkaline arsenite. Upon evaporating a considerable quantity of the water and applying Marsh's test I had no difficulty in discovering the presence of this poison. No doubt the quantity could be estimated by the methods adopted for ascertaining the amount present in beers. The gas liberated in the Marsh's apparatus is, with precautions, passed through a piece of hard narrow tubing heated at one point. The mirror produced is then compared with similar mirrors obtained from solutions containing known quantities of arsenic.

## Q. DETECTION AND ESTIMATION OF SULPHURETTED HYDROGEN

The most delicate test for the presence of this gas is the smell. Where this is pronounced the addition of a little acid and of a few drops of the solution of lead acetate may produce a marked discoloration. Some waters have a decidedly suggestive smell of this gas, yet do not give any positive reaction with lead acetate. In one such case the first portion of the distillate from the acidified water gave a decided reaction when a lead salt was added. The hydric sulphide somewhat rapidly absorbs oxygen, with liberation of sulphur and the disappearance of the odour. This change probably takes place in stages, sulphur compounds, sulphites, thiosulphates, &c. being formed which possess the power of decolourising iodine. The following quantitative test gives the total iodine absorbed, and for practical purposes may be expressed in terms of $H_2S$.

*Very faintly* acidulate 500 c.c. of the water with dilute sulphuric acid, add a little solution of starch, and run in a centinormal solution of iodine until a blue tint appears. A little of the water is then added from a graduated tube until the colour disappears. The iodine used corresponds to the $H_2S$, &c., present in 500 c.c. plus half the amount required to decolourise the iodide of starch.

The following is an example of such a determination. The water was derived from the boulder clay in the north-west of Essex, and had a strong odour of sulphuretted hydrogen.

To produce a blue tint with 500 c.c. of the water, to which 5 c.c. of starch solution had been added, 9 c.c. of centinormal solution of iodine were required. The addition afterwards of 8 c.c. of the water decolourised the solution.

The reaction being $I_2 + H_2S = 2HI + S$, 1 c.c. of the iodine solution was equivalent to 0·17 mlgr. of $H_2S$ and $500 + \frac{8}{2}$ c.c. contained $9 \times 0{\cdot}17$ mlgr. of $H_2S$ = 3·1 mlgr. per litre.

Alkaline sulphur waters which have undergone change by exposure to the air may be evaporated to dryness after the addition of a little sodium hydrate and potassium nitrate, gently ignited, and the $SO_4$ in the residue determined. The difference between the sulphates in the original water and in the ignited residue is due to the sulphur existing in other forms of combination.

In a potable water, polluted with soakage from a gas-works, it was found that a considerable amount of iodine was decolourised by the contaminated water, whereas the pure water practically absorbed no iodine. The ammonia and the total sulphates also increased in the polluted water.

# CHAPTER XIII

## ESTIMATION OF THE SALINE CONSTITUENTS

It has previously been stated that for many purposes it is desirable to know something of the nature of the saline constituents of a water. Without such analyses as will give this information the variations in the character of waters from certain sources cannot be followed or understood. The complete analysis of waters from definite geological strata gives information of considerable scientific importance, and it is much to be regretted that records of so few analyses of this character are available. In studying the waters derived from the Thanet sands and the chalk in the various parts of Essex, I have had to make hundreds of such analyses, and have gradually improved the processes until now several analyses can be made in the time formerly occupied in making one. The results are sufficiently accurate for all practical purposes, and certainly more accurate than many analyses carried out by more tedious methods.

It is to be regretted that many analyses published are obviously erroneous, and consequently the results are misleading. This is exemplified by the following analyses of a deep-well water which were submitted to me some time ago, and a study of them will not be without interest. When the well was first sunk a sample was submitted to an analyst, and his results are recorded in column 1. After the completion of the works a sample was sent to another well-known analyst, and his results are recorded in column 2. This differed so much from No. 1 that a further sample was submitted to a third analyst, and his results are recorded in column 3. Some years later, when I examined the water, the results of the three previous analyses were submitted for my opinion. My results are recorded in column 4.

ANALYSES OF WATER FROM A DEEP WELL.
IN GRAINS PER GALLON

| | No. 1 | No. 2 | No. 3 | No. 4 |
|---|---|---|---|---|
| Calcium carbonate | — | ·475 | ·595 | ·3 |
| Calcium chloride | ·71 | — | — | — |
| Magnesium carbonate | — | ·199 | ·161 | ·10 |
| Magnesium chloride | ·04 | — | — | — |
| Sodium carbonate | 46·40 | 43·347 | 45·885 | 45·6 |
| Sodium sulphate | — | — | ·644 | — |
| Sodium chloride | 16·72 | 2·529 | 16·726 | 17·4 |
| Potassium chloride | — | 19·039 | — | — |
| Sodium nitrate | — | 2·123 | ·147 | ·2 |
| Alumina and silica | — | ·648 | ·588 | 1·4 |
| Error, &c. | — | ·061 | — | |
| Total solids by weighing | 65·73 | 65·799 | 64·743 | 65·0 |
| Total solids by addition | 63·87 | 68·421 | 64·746 | 63·6 |

In the first analysis the acids and bases have been combined in such a way as to indicate that the water contained the chlorides of calcium and magnesium in the presence of a large excess of sodium carbonate; potassium salts and sulphates were not detected, and the cause of the difference between the total solids found by weighing the water residue and found by addition of the constituents, is not referred to.

In the second analysis, which is much more pretentious, the solids by addition amount to much more than by actual determination, a certain proof of some error. The water examined before and after No. 2 contained no potassium salts and the merest trace of nitrates, and the same condition obtained when I examined the water. Inasmuch as the total solids, directly determined, have remained practically the same, there is very little doubt that the water remains constant in character and the differences are due to errors in the analyses.

No. 3 shows the presence of a trace of sulphate. This was not found in either No. 1 or 2. The absence of any such trace is so singular that in my analysis I examined the concentrated water, but found no indications of its presence. The chlorine in the chlorides was found in Nos. 2 and 4 to be a little higher than in Nos. 1 and 3.

Where such variations are found in analyses made by well-known chemists, it is obviously useless giving results pretending to show an approach to accuracy beyond the first place of decimals.

For practical purposes it almost invariably suffices to determine the calcium and magnesium and the ions of carbonates, sulphates, chlorides, and nitrates, but the potassium and sodium may be determined where it is desired either to make a more complete analysis or to check off the results. On occasions other determinations may be necessary, as of Fe, Pb, Al, Br, I, $SiO_2$, &c.

## DETERMINATION OF THE TOTAL SOLIDS

The estimation of the total solids is usually regarded as one of the simplest in the domain of water analyses, whereas it is one requiring the greatest amount of skill and experience. In comparing results obtained by different analysts from the same water, the discrepancies are often most marked, yet it is not unusual to find the results expressed to the one-thousandth part of a grain per gallon.

I use platinum dishes capable of holding about 60 to 70 c.c. and weighing about 35 grammes. After being polished with a little sand-soap and thoroughly cleansed with distilled water, the dish is placed on the water bath for a few minutes, care being taken that nothing splashes on to the bottom of the dish. It is then removed, dried with a clean absorbent cloth, placed in a hot-air oven and kept at 180° C. for a few minutes. Finally it is placed in a desiccator, allowed to stand therein for five minutes, and then weighed to 0·1 mlgr. The tare being recorded, it is again placed on the water bath. A 100 c.c. stoppered flask is filled with the water to be examined and about 25 c.c. poured into the dish. When this has nearly all evaporated, a similar quantity is added and so on until all is in the dish. The flask is then rinsed with a few c.c. of distilled water which are poured into the dish. The dish is allowed to remain about a quarter of an hour on the bath after it appears dry, is then carefully wiped outside, placed in the air oven at 180° C. for an hour, removed to the desiccator, and five minutes later weighed.

If much time is lost in weighing, and the residue is obviously absorbing moisture, as indicated by the increasing weight, the dish should be returned to the air oven for five or ten minutes and again allowed to cool, and weighed. I have adopted 180° C. because at this temperature magnesium sulphate retains a definite proportion of water and calcium sulphate loses the whole of its water of crystallisation, the results consequently being much more uniform and satisfactory than at a lower temperature. They are always sufficiently accurate for the quantitative estimation of the saline constituents, and it is very rarely necessary to check the results by converting the salts into sulphates, as described later.

After weighing, the bottom of the dish may be gently heated over a naked Bunsen flame to ascertain whether the residue chars or undergoes any change on heating. Weighing after ignition to ascertain the 'loss' appears to me to be a waste of time, as it gives no information of any value.

The water residue, after moistening with hydrochloric acid, may be used for examination by the flame test, using a blue glass for detecting potassium, or the spectroscope for the detection of the rarer metals. Or it may be used for testing for traces of lead, iron, manganese, or zinc, where the original water gave no decided reaction indicating the presence of these metals.

Certain waters contain magnesium chloride, and when such is the case some chlorine is lost during the drying process. A correction may be made for this by estimating the chlorine in the dried residue, and adding to the total solids the amount of chlorine lost, less its equivalent of oxygen. As magnesium sulphate retains one molecule of water when dried at 180° C., this is included in the undetermined portion. Calcium chloride is not rendered absolutely anhydrous at 180° C., nor is magnesium nitrate. Magnesium carbonate also appears to retain a little water, the dried precipitate being a hydrated carbonate. For these and other reasons the total solids obtained by drying can never exactly correspond with the total of the ions as directly determined. I prefer, therefore, to give the results of all the determinations without attempting any corrections.

A better confirmation of the analytical results may possibly be obtained by moistening the residue left upon evaporation with dilute sulphuric acid (1 in 4), and carefully heating on a hot plate until fumes are no longer evolved. The residue is then gently ignited and weighed. The result gives the total weight of all the bases as sulphates, plus the weight of the silica. This is no real check on the determinations, and I doubt very much the utility of the process. I have tried it on several occasions when there was an unusual discrepancy between the total of the saline constituents and the total solids, but it has never led to the detection of any error, or thrown any light on the cause of the discrepancy.

Another method which I used systematically for some time when taking the total solids of water containing $MgSO_4$, $MgCl_2$, or $CaCl_2$, was to add to the water before evaporation a quantity of decinormal solution of sodium carbonate, rather more than sufficient to decompose any of the above salts which might be present, and after weighing the dried residue to deduct the weight of the sodium carbonate added. Although, as a rule, the total solids as thus determined approached more nearly the total of the saline constituents of the water, and the process of weighing was facilitated, I have of late discontinued it, not regarding the results as of any more value than those obtained in the usual way.

With unpolluted waters the results of the direct and indirect determinations closely correspond ; it is only with polluted waters that the difference between the total solids and the total of the saline constituents is at all marked, and such waters are rarely worth the trouble of an extended examination.

## ESTIMATION OF CALCIUM AND MAGNESIUM

These metals are determined in the same portion of water, the magnesium being estimated after the removal of the calcium.

No special apparatus or reagent is required for the calcium estimation.

The amount of water taken is usually 200 c.c., but 100 will suffice if the hardness of the water exceeds 20 degrees.

The water is placed in a flask of about 400 c.c. capacity, and, 1 c.c. of dilute hydrochloric acid having been added, it is concentrated by evaporation to about 50 c.c. Whilst still hot, dilute solution of ammonia is dropped in until the liquid has a distinct ammoniacal odour,[1] then 2 c.c. of a saturated solution of ammonium oxalate are added and the mixture is allowed to stand on the hot plate for one hour. The clear liquid is then passed through a small exhausted filter paper and the precipitate finally washed on to the paper. The flask is rinsed out three or four times with small quantities (about 5 c.c.) of distilled water, the rinsings being passed through the filter. Finally the last trace of ammonium oxalate is removed from the paper and precipitate by a fine stream of water from a wash-bottle. The filtrate should not exceed 100 c.c. A little calcium oxalate adheres to the side of the flask, but this is of no consequence, as the next step is to wash the precipitate from the filter back into this flask. This is done by perforating the filter and washing the precipitate through. Drop dilute hydrochloric acid on to the filter paper and wash with boiling distilled water. Repeat this thrice. By this means all the calcium oxalate in or on the filter paper is washed into the flask. The liquid in the flask may measure 40 to 50 c.c. Add to it 5 c.c. of dilute sulphuric acid and heat to about 50° C. The whole of the calcium oxalate is dissolved.

Now run in volumetric solution of potassium permanganate (1 c.c. = 0·1 mlgr. O) until a faint pink tint is produced. Note the number of c.c. required. From the amount of oxygen consumed the amount of calcium present is easily calculated.

---

[1] If much magnesium is present, turbidity may ensue upon the addition of the alkali, in which case more acid must be added, and ammonia again dropped in until alkaline.

$$CaC_2O_4 + H_2SO_4 + O = CaSO_4 + 2CO_2 + H_2O.$$

From this equation it is obvious that 16 parts of oxygen correspond to 40 of calcium, therefore each c.c. of the permanganate solution corresponds to 0·25 mlgr. of calcium. In other words, the number of c.c. of permanganate solution used, divided by 4, gives the amount of calcium in milligrams in the quantity of water used.

In exceptional cases where the water contains an appreciable quantity of iron, a faintly coloured precipitate appears when the liquid is rendered alkaline with ammonia. This may be filtered out if thought desirable, but my experience leads me to doubt whether this is necessary.

As previously stated, the magnesium is determined in the filtrate from the calcium oxalate precipitate. The filtrate is allowed to get cold and made up to exactly 100 c.c. The amount of this required for the experiment depends upon the amount of magnesium present. I find it best to use such a quantity as contains approximately 0·5 mlgr. Mg.

To ascertain about the quantity to be taken, place a few c.c. in a test-tube and add 2 or 3 drops of the solution of ammonium phosphate. If a copious precipitate is produced on shaking, 25 c.c. or less of the solution will be required; if only a faint precipitate, 50 c.c. or more may be used. Or 25 c.c. may be first used, and if this is too much or too little, a second experiment can be made using the right quantity of liquid.

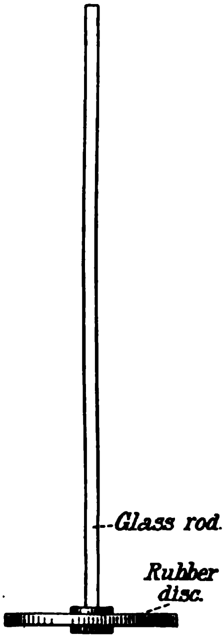

FIG. 9

The apparatus required includes:

1. A long stirrer or plunger, made by cementing or otherwise

fixing on the end of a glass rod a piece of sheet india-rubber a little less in diameter than the 100 c.c. cylinder in which the experiment is to be made.

2. A sheet of white cardboard with black dots as shown in fig. 7.

The only special reagent is a solution of magnesium sulphate each c.c. of which corresponds to 0·25 mlgr. magnesium. Take 25 c.c. of the filtrate from the calcium precipitate, and dilute it to 100 c.c. in a Nessler cylinder. Add 2 c.c. of an ammoniacal solution of ammonium phosphate, and immediately commence a rapid up-and-down movement with the plunger. This must be continued for two minutes. The magnesium ammonium phosphate produced is in such an exceedingly fine state of division that it shows very little tendency to deposit. After standing a few seconds for the air bubbles to rise, pour the liquid steadily and slowly down the side of a short 50 c.c. graduated cylinder standing upon the black spots on the white paper until a point is reached when the dots can no longer be separately distinguished. Note the number of c.c. required and repeat the determination two or three times, and take the average. The difference in the readings, with a little experience, is very small. Work in diffused white light and make the various comparisons in the same position and in the same light.

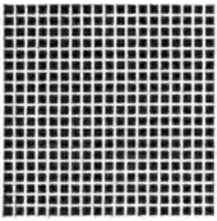
Fig. 10

Now repeat this process, using 98 c.c. of distilled water to which have been added 2 c.c. of the standard magnesium solution. In a cylinder 2·5 cm. in diameter, from 20 to 22 c.c. of this solution are required (according to the light) to obscure the spots on the cardboard disc. If the liquid being examined takes much less, or much more, than this, prepare a fresh solution, stronger or weaker as the case may be, and repeat the experiment. If, for example, the first dilution obscures the dots with only 10 c.c., it is obviously about twice the strength required; while if, on the other hand, it requires about 40 c.c., it is only half the strength.

It is not necessary to prepare a fresh standard, as the one first made merely requires stirring for use in the second experiment. The following details of a determination will illustrate how the calculations based on the experimental results are made.

Two hundred c.c. of water were originally taken. After precipitation of the calcium, the liquid was made up to 100 c.c. The preliminary test showed that the solution would require dilution; 25 c.c. diluted to 100 c.c. were compared with a standard solution containing 0·5 mlgr. Mg in 100 c.c.

AMOUNTS OF SOLUTION REQUIRED TO OBSCURE THE DISC

| | Standard | Solution |
|---|---|---|
| | 22 | 24·5 |
| | 21·5 | 25 |
| | 22 | 24 |
| Mean | 21·8 | 24·5 |

The standard was obviously the stronger in the proportion of 24·5 to 21·8; the 100 c.c. of solution used for the experiment therefore contained $\frac{21 \cdot 8}{24 \cdot 5} \times 0 \cdot 5 = 0 \cdot 445$ mlgr. Mg.

This amount was contained in 25 c.c. of the stronger solution which represented 50 c.c. of the original water, and therefore the original water contained 0·89 mlgr. Mg in 100 c.c. The following series of estimations show the degree of accuracy obtainable by these processes.

DETERMINATION OF CALCIUM

| Amount taken | Amount found |
|---|---|
| 4·0 mlgr. | 4·1 mlgr. |
| 8·0 „ | 7·9 „ |
| 16·0 „ | 16·1 „ |

DETERMINATION OF MAGNESIUM

| Amount taken | Amount found |
|---|---|
| ·25 mlgr. | ·245 mlgr. |
| ·5 „ | ·51 „ |
| ·6 „ | ·62 „ |
| 2·5 „ | 2·5 „ |

### DETERMINATION OF CALCIUM AND MAGNESIUM

| 100 c.c. of the water contained in mlgr. | | Found | |
|---|---|---|---|
| Ca | Mg | Ca | Mg |
| 4·0 | 1·43 | 3·96 | 1·43 |
| 4·0 | 1·43 | 3·84 | 1·38 |
| 8·0 | ·0 | 8·2 | ·0 |
| ·8 | ·0 | ·8 | ·0 |
| 12·0 | 4·3 | 11·9 | 4·2 |
| 10·0 | 2·9 | 9·8 | 3·0 |
| 8·0 | 1·4 | 8·0 | 1·4 |
| 10·0 | 2·9 | 10·1 | 3·0 |
| 8·0 | ·0 | 7·9 | ·0 |

I have made several hundreds of analyses by these methods, and on several occasions have determined the calcium and magnesium gravimetrically. The results have always been quite satisfactory, and the time taken is only a tithe of that required for a gravimetric analysis.

To ascertain the length of time necessary for the complete precipitation of the calcium by the ammonium oxalate, three experiments were started, and the calcium and magnesium determined in each after standing one, two, and fourteen hours respectively. The results were as under:

| Amounts of Ca and Mg taken in mlgr. | | Time of standing | Amounts of Ca and Mg found in mlgr. | |
|---|---|---|---|---|
| Ca | Mg | | Ca | Mg |
| 9·3 | 2·0 | 1 hour | 9·3 | 1·92 |
| 9·3 | 2·0 | 2 hours | 9·3 | 2·04 |
| 9·3 | 2·0 | 14 hours | 9·3 | 1·92 |

Obviously, therefore, there is no necessity for the liquid to stand more than one hour after the addition of the ammonium oxalate. The amount of ammonium oxalate added, provided it is in excess, is of little consequence. The amount given in the text more than suffices for any water which can be called 'potable.'

### ESTIMATION OF POTASSIUM AND SODIUM

An accurate determination of these metals requires great care. The method frequently adopted of calculating the two from the weight of the mixed chlorides, and the determination of the chlorine therein, is absolutely unreliable, since when such small quantities are being dealt with, an error of even one-tenth of a milligram in either experiment seriously affects the result. In the results of analyses submitted to me, whilst the calcium and magnesium determinations have usually corresponded closely, the amounts of potassium and sodium have differed greatly, and this I attribute to the above method of analysis having been adopted.

The following results were obtained in attempting to determine the amounts of potassium and sodium by this method in a solution containing also calcium and magnesium salts. The formulæ employed in the calculations were:

$a =$ the weight of mixed chlorides obtained,
$b =$ the amount of chlorine therein.
Let $x =$ the amount of potassium chloride in $a$;

then $$x = \frac{0 \cdot 6065\, a - b}{0 \cdot 1311};$$

also $x \times 0 \cdot 5246 =$ the amount of potassium,
$(a - x) \times 0 \cdot 3935 =$ the amount of sodium.

| | Amount taken in gram. | Amount found 1 | 2 | 3 |
|---|---|---|---|---|
| Potassium . . . . | ·01395 | ·0169 | ·0165 | ·01275 |
| KCl . . . . | ·0266 | ·0322 | ·0315 | ·0243 |
| Sodium . . . . | ·01535 | ·0129 | ·1358 | ·01495 |
| NaCl . . . . | ·0390 | ·0328 | ·0345 | ·0380 |

The results are far from being accurate, and using smaller quantities of potassium salts the inaccuracies were even greater. As the amount of potassium in potable waters is usually very small, I am persuaded that the process is useless for the purpose of water analysis.

The following process for separating the potassium and sodium salts and estimating the amount of each I have finally adopted after a trial extending over several years. It gives results which are more reliable than any others I have tried. Its satisfactory character will be demonstrated later by the results of experiments made for this purpose.

As it is desirable to know the amount of magnesium and of sulphates in the water before commencing the determination of the potassium and sodium, it is better to complete the estimation of the magnesium and of the sulphates whilst the water required for the potassium and sodium estimation is being evaporated.

Take 200 c.c. of the water and evaporate in a platinum dish on the water bath to about 50 c.c. Then add sufficient solution of barium chloride (1 c.c. = 2 mlgr. $SO_4$) to decompose all the sulphates present, and after a little further evaporation add 2·5 c.c. of fresh lime-water, made from pure calcium oxide, for each mlgr. of Mg contained in the water. Continue the evaporation until only about 10 c.c. remain. Filter through a very small exhausted filter paper into a test-tube, and wash the residue in the dish and on the paper with successive small quantities of hot distilled water. Not more than 10 or 15 c.c. need be used. Heat the filtrate to boiling point, add drop by drop solution of ammonium carbonate until it produces no further precipitate, then add a droplet of solution of ammonium oxalate. The precipitate at boiling-point falls rapidly, and after standing a quarter of an hour the clear liquid is filtered through a small exhausted paper into a dish, and the residue washed with a few c.c. of water. Evaporate the filtrate to dryness on the water bath, and gently ignite to drive off all the ammonium salts. When the dish is cool moisten the residue with one or two drops of strong hydrochloric acid and evaporate to dryness. If the water contains more than a trace of nitrates, this process should be repeated twice to convert all the nitrates into chlorides. Dissolve the residue in about 5 c.c. of water, filter as before into a small tared platinum crucible or dish, evaporate to dryness on the water bath, then heat to 120° C. for a few minutes, allow to cool, and weigh. The results give the weight of the potassium and sodium as chlorides.

Dissolve the residue in the smallest possible quantity of water, and add 1 c.c. of the solution of platinic chloride for every 30 mlgr. of the mixed chlorides. This ensures the conversion of the whole of the chlorides into double salts. Evaporate until only a moist crystalline residue remains. When cold pour over it 5 c.c. of strong methylated spirit, allow to stand ten minutes, and pour off the spirit, passing it through a very small filter. Repeat this process again and again, transfer the precipitate to the filter, and continue the addition of spirit until the washings are quite free from colour. The first and second washings may be transferred to the bottle for waste platinum solutions and residues; the subsequent washings should be collected separately, so that the point may easily be recognised at which the washings become colourless. Let the filter dry in a warm place. Dissolve the potassium platinic chloride in a little hot water, washing the filter thoroughly. To the coloured solution, which need not measure more than 10 to 20 c.c., add a very minute quantity of a zinc-copper couple, made with zinc dust (as described under nitrates), and allow to stand until the liquid is quite free from colour. Pour off the clear liquid into a porcelain dish, wash the residue with successive small quantities of water, add the washings to the liquid, and determine the chlorine therein volumetrically.

The chlorine found multiplied by 0·368 gives the amount of potassium present; multiplied by 0·701 it gives the weight of potassium chloride. The latter, deducted from the weight of the potassium and sodium chlorides, gives the amount of sodium chloride.

The following determinations show the accuracy of this method of determining small quantities of potassium. The salt used was potassium nitrate.

| Weight of potassium taken | | Amount found |
|---|---|---|
| ·0056 gram. | | ·0053 gram. |
| ·0056 ,, | | ·0058 ,, |
| ·0056 ,, | (with a little sodium salt) | ·0053 ,, |
| ·0056 ,, | ,, ,, | ·0052 ,, |

In the following determinations a mixture of potassium nitrate and sodium carbonate was used.

| Taken | | Found | |
|---|---|---|---|
| K | Na | K | Na |
| ·0056 gram. | ·0476 gram. | ·00566 gram. | ·0469 gram. |
| ·0014 ,, | ·0030 (+ $MgSO_4$ + $CaCl_2$) | ·0015 ,, | ·0029 ,, |
| ·0112 ,, | ·0306 ,, ,, | ·0106 ,, | ·0308 ,, |
| ·01395 ,, | ·0390 ,, ,, | ·01375 ,, | ·0388 ,, |

The amount of potassium salts found in potable waters is usually so small that it is rarely worth the trouble of determining. If upon applying the flame test the potassium coloration is very evanescent, and if the total saline constituents, assuming potassium to be absent, closely approach the total solids obtained by weighing, it is not necessary for any practical purpose to attempt the estimation of the potassium.

The quantities found in waters from different sources will be found in a later table. Possibly it is not without significance that most potassium is found in water containing an excessive amount of nitrates.

The following table is taken from records of the analyses of a series of samples of water taken at monthly intervals from a chalk well which was affected by the infiltration of sea-water, and which therefore contained considerable amounts of magnesium salts.

The amount of water used was invariably 200 c.c., and the first two columns give the actual results (in mlgr.) obtained, from which those in the second two columns are calculated per 100 c.c.

| KCl + NaCl obtained | Cl in platinic salt as determined | K calculated | Na per 100 c.c. |
|---|---|---|---|
| Mlgr. | Mlgr. | Mlgr. | Mlgr. |
| 74·0 | 5·5 | 1·0 | 13·8 |
| 80·5 | 6·5 | 1·2 | 14·95 |
| 63·7 | 5·4 | 1·0 | 11·3 |
| 31·0 | 3·6 | ·65 | 5·6 |
| 80·6 | 7·6 | 1·4 | 14·8 |
| 70·5 | 5·7 | 1·05 | 13·1 |
| 64·5 | 4·9 | ·9 | 12·0 |
| 68·0 | 5·5 | 1·0 | 12·6 |
| 62·5 | 4·7 | ·86 | 11·2 |

## ESTIMATION OF ACIDS OR ANIONS

### CARBONATES (NEGATIVE ION OR ANION, $CO_3$)

The following process for the estimation of $CO_3$ necessitates the use of a tall white glass cylinder of 250 c.c. capacity, of a sufficiently long agitating rod with a rubber disc at the end similar to that used in the magnesium determination, of a standard solution of sulphuric acid (1 c.c. = 2 mlgr. $CO_3$), and of a very delicate and dilute solution of methyl orange. The latter indicator varies much in delicacy, and a sample should be obtained giving a decided reaction with 0·1 c.c. of the standard acid in 200 c.c. of freshly distilled water. The amount of indicator used is also a matter of importance. With too much the end reaction is obscured, with too little the reaction is not sufficiently definite. Before applying the process, a few experiments should be made in order to acquire the requisite skill in observing the change from orange to red. At first this is a little difficult, but subsequently it becomes comparatively easy, and the results given below show that they are concordant and reliable.

Into the cylinder above mentioned, introduce 5 or 10 c.c. of the standard acid and sufficient of the dilute methyl orange solution to give it a decided red colour. Then pour in slowly, and with continuous agitation, the water to be examined until the red colour is discharged and the paler yellow tint appears. Note the number of c.c. of water added, and pour in more water to the 205 or 210 c.c. mark according to the amount of acid used. Now run in the acid from a burette until the red tint again appears, and note the amount of acid used. Finally pour in more of the water until the red tint is just discharged. The readings on the graduated jar will give the amount of water used.

The following are the details of an experiment:

Acid taken, 5 c.c. = 10 mlgr. $CO_3$.

Water required to remove the red tint, 165 c.c.

The water, therefore, contained approximately 6 mlgr. $CO_3$ in 100 c.c.

The water when made up to 200 c.c. required 1·2 c.c. more acid to restore red colour, and 8 c.c. of water removed the red tint.

$$\frac{200 + 208}{2} \text{ c.c. water} = 2 \times 6{\cdot}2 = 12{\cdot}4 \text{ mlgr. } CO_3.$$

$$\therefore 100 \text{ c.c. water contained } 6{\cdot}07 \text{ mlgr. } CO_3.$$

The water used was distilled water containing 6 mlgr. $CO_3$ as sodium carbonate in 100 c.c.

In a series of experiments in which only the first reading, the production of a red tint, was recorded, the following results were obtained :

| Mlgr. of $CO_2$ in 100 c.c. | | Mlgr. of $CO_2$ found |
|---|---|---|
| 2·66 | in distilled water | 2·7 |
| 5·3 | ,, | 5·4 |
| 5·3 | ,, | 5·4 |
| 7·9 | ,, | 8·1 |
| 10·6 | ,, | 10·8 |
| 13·3 | ,, | 13·5 |
| 13·3 | ,, | 13·2 |
| 26·6 | ,, | 27·0 |

This method of observation gave, with one exception, results uniformly too high, which fact led to the adoption of the method described, in which the mean of two observations is taken. Using this process the following results were obtained :

| Mlgr. $CO_2$ in 100 c.c. | | | Mlgr. $CO_2$ found |
|---|---|---|---|
| 9·6 | in distilled water | | 9·5 |
| 9·6 | ,, | | 9·6 |
| 6·9 | ,, | | 6·96 |
| 2·8 | ,, | | 2·8 |
| 2·8 | ,, | + $CaCl_2$ + $MgSO_4$ | 2·7 |
| 5·6 | ,, | ,, ,, | 5·52 |
| 2·9 | ,, | ,, ,, | 2·96 |
| 40·4 | ,, | ,, ,, | 40·2 |
| 9·6 | ,, | ,, ,, | 9·5 |
| 5·9 | ,, | + $Na_2SO_4$ | 5·84 |
| 2·1 | ,, | ,, | 2·16 |
| 5·1 | as $CaCO_3$ dissolved in water + $CO_2$ | | 5·2 |

The above results are, in my opinion, conclusive proof of the reliability of this method. The following modification may be preferred by those who experience a difficulty in defining the end reactions.

Take 200 c.c. of the water, add the methyl orange and run in the acid until an obvious red tint appears. Now divide the whole into two portions in tall Nessler glasses of exactly the same tint of glass, and into one pour, from a narrow measuring cylinder or burette, more of the water until the red tint has disappeared. By comparison with the adjacent cylinder this is readily seen. The total water used corresponds to the amount of acid used. For example :

Water taken, 200 c.c.

Acid required to give a red tint, 5·0 c.c.

Water added to half to destroy red tint, 4·5 c.c.

204·5 c.c. water = 10 mlgr. $CO_3$; ∴ 100 c.c. = 4·89 mlgr. $CO_3$.

The water used contained 4·9 mlgr. $CO_3$ per 100 c.c.

As previously stated, the accuracy of the process depends chiefly on the delicacy of the methyl orange and on the amount of indicator used. I keep a strong solution of methyl orange and from this make a dilution of such strength that two drops (from the end of a pipette fixed in the cork of the containing bottle) suffice for each experiment. This imparts a slight but distinctly obvious yellow tint to 200 c.c. of water. The cylinders used should be of colourless glass, and a turbid water should be filtered before being titrated.

## SULPHATES (ANION, $SO_4$)

The $SO_4$ may be determined rapidly by either of the following methods.

(1) **Turbidimetric.**—This requires the use of Nessler cylinders and a stirring rod with rubber disc on the end as used in previously described turbidimetric methods, dilute hydrochloric acid, solution of barium chloride, and a standard solution of sulphuric acid, the same as used in the $CO_3$ determination (1 c.c. = 3·2 mlgr. $SO_4$).

The water to be examined should not contain more than 5 mlgr. $SO_4$ in 100 c.c. If it does, it should be diluted until the dilution contains between 3 and 4 mlgr. in that quantity.

Take 100 c.c. of distilled water in a Nessler cylinder, add 1 c.c. of the standard solution of sulphuric acid, 2 c.c. of dilute hydrochloric acid, and 1 c.c. of the barium chloride solution. Agitate vigorously and continuously for two minutes. Set aside.

Next take 100 c.c. of the water, or a known dilution, add the hydrochloric acid and barium chloride and agitate as before.

By aid of a graduated cylinder placed over the cardboard disc described under the determination of magnesium, ascertain the respective depths of the columns of the turbid mixtures required to entirely obliterate the squares, or the amount which leaves them just recognisable. If there is any considerable difference, the water must be diluted or concentrated until a sufficiently close approximation is obtained. The average of a number of readings should be taken.

If $a$ = the average number of c.c. of the standard,
$b$ = the average number of c.c. of the water,

then the amount of $SO_4$ in 100 c.c. of the water (or dilution) used is $3{\cdot}2 \times \frac{a}{b}$.

For example, a solution of a sulphate known to contain 3·8 mlgr. $SO_4$ in 100 c.c. was compared with the standard containing 3·2 mlgr. $SO_4$ per 100 c.c. The readings were as under:

| | Standard | Water | |
|---|---|---|---|
| | 31 | 25·5 | reading to obliteration of squares |
| | 28 | 24·0 | ,, to bare discernment of squares |
| | 31 | 25·5 | ,, to obliteration of squares |
| Mean | 30 | 25·0 | |

$$3{\cdot}2 \frac{30}{25} = 3{\cdot}84$$

The following experiments show the accuracy of the process.

| $SO_4$ calculated in 100 c.c. Mlgr. | $SO_4$ found. Mlgr. | $SO_4$ calculated in 100 c.c. Mlgr. | $SO_4$ found. Mlgr. |
|---|---|---|---|
| ·95 | ·91 | 3·0 | 2·9 |
| 1·235 | 1·15 | 6·6 | 6·6 |
| 1·52 | 1·44 | 10·5 | 10·4 |
| 2·0 | 2·07 | | |

For waters containing small quantities of sulphates this very rapid process leaves nothing to be desired. Any slight error in the determination, however, is increased in calculating out the results in proportion to the dilution; hence, when the water to be examined contains over 20 mlgr. $SO_4$ per 100 c.c., as can be readily ascertained by a rough turbidimetric experiment, the volumetric method next to be described may be preferred.

(2) **Volumetric Method.**—To perform this to the best advantage the amount of $SO_4$ in the water must be approximately known. This approximation is ascertained by the turbidimetric

method. 100 c.c. or 200 c.c. of the water may be employed. This is evaporated in a flask to about 40 c.c. and a little dilute hydrochloric acid added. After boiling to drive off any $CO_2$, the volumetric solution of barium chloride is added in slight excess of that required to precipitate the whole of the $SO_4$. After standing about ten minutes a very dilute solution of ammonia (free from carbonate) is added drop by drop until the liquid is faintly alkaline. It is again boiled for a few seconds and the volumetric solution of potassium chromate added, 0·5 c.c. at a time, until the supernatant liquid has a decided yellow colour. The colour must be quite distinct. Allow to stand for a few minutes, then filter into a Nessler cylinder and dilute to 50 c.c. When cold the excess of chromate is determined by dropping the volumetric solution of chromate into 50 c.c. of water until the colour matches that of the filtrate. All the data required for determining the $SO_4$ in the water are now available. Using 200 c.c. of water, as I generally do, the following formula gives the amount of $SO_4$ in 100 c.c.

Let $a$ = the number of c.c. of barium chloride added,
$b$ = the number of c.c. chromate required to precipitate the excess of barium and colour the liquid, and
$c$ = the excess of chromate solution in c.c.

then $a - (b - c) = a + c - b$ = number of mlgr. $SO_4$ in 100 c.c.

The following is an example of a determination:

By the turbidimetric test about 10 c.c. of the water to which acid and barium chloride had been added obscured the squares on the test disc. As about 30 c.c. are required with a water containing 3·2 mlgr. $SO_4$ in 100 c.c., the sample evidently contained about three times that amount, i.e. about 10 mlgr. per 100 c.c. In the experiment, therefore, 12 c.c. of solution of barium chloride were added. Afterwards 2·5 c.c. of chromate solution gave a distinct colour to the supernatant water, and the excess of chromate was found to correspond to 0·9 c.c. Therefore

$$a = 12,\ b = 2{\cdot}5, \text{ and } c = 0{\cdot}9,$$

and $$a + c - b = 10{\cdot}4 \text{ mlgr. } SO_4 \text{ in 100 c.c.}$$

The following are experimental results obtained showing the very approximate accuracy of the process:

| $SO_4$ in 100 c.c. water. Mlgr. | $SO_4$ found. Mlgr. |
|---|---|
| 5·7 | 5·8 |
| 6·4 | 6·4 |
| 7·4 | 7·5 |
| 8·0 | 7·9 |
| 11·4 | 11·6 |
| 12·5 | 12·4 |
| 14·4 | 14·2 |
| 24·0 | 24·4 |
| 60·0 | 60·6 |

Occasionally I find the tint of the final filtrate differs from that of the diluted standard. In such cases it is apparently advisable to add to each a few drops of hydrochloric acid, to convert the chromate into bichromate. The tints then are sufficiently alike to admit of the process being more satisfactorily completed.

Where the $SO_4$ present is far too large for accurate estimation by the turbidimetric method, I prefer to estimate it gravimetrically.

## SILICA ($SiO_2$)

If it is desired to estimate the amount of silica present in a water, ½ or 1 litre should be rendered slightly acid with hydrochloric acid and evaporated to dryness in a platinum basin. The residue is moistened with hydrochloric acid and allowed to stand half an hour. The dish is then placed on the water bath and about 20 c.c. of water added. After a few minutes the acid solution and precipitate are transferred to a small filter and the latter is washed with hot water acidulated with hydrochloric acid until the filtrate no longer gives any cloudiness with solution of barium chloride. The filter paper is then dried, burnt and ignited in a tared platinum crucible, and the silica weighed.

It is very rarely necessary to determine the silica unless for some reason a very complete analysis is required. I have occasionally estimated it when I have found the total of the saline constituents to fall markedly short of the total solids as ascertained by evaporation and weighing.

### ALUMINA ($Al_2O_3$)

Any alumina present may be determined in the filtrate from the silica precipitate. The liquid is evaporated to a low bulk (about 22 c.c.), a drop of nitric acid added and boiled to oxidise any trace of iron present. Add a little solution of ammonium chloride to prevent the precipitation of magnesia, and a very slight excess of solution of ammonia. On again boiling the alumina is precipitated, destitute of colour if pure, but of a brown tint if iron is present. The precipitate is transferred to a small filter, thoroughly washed, dried, and finally ignited in a tared crucible. The heating should be continued over the blowpipe for about five minutes. The weight of the residue will be that of the alumina plus any ferric oxide present. As the iron in the water will have previously been determined, the amount of ferric oxide present can be calculated and deducted; the remainder will represent the amount of alumina in the quantity of water originally evaporated.

The amount of alumina present in potable waters is usually infinitesimal, and unless some preliminary test has revealed its presence in appreciable quantity, no useful purpose is served in attempting to estimate it.

### RESULTS OF ANALYSES.

The results obtained in making an analysis of a water for sanitary purposes are usually tabulated, and the forms employed are very varied. The one given in a later section is used in my laboratories, and is as intelligible as any I have seen, giving all the data necessary for forming an opinion on the quality of a water, from the chemical point of view.

When a more complete analysis has been made, and the chief anions and cations quantitatively determined, the analyst may simply give the results obtained or combine the ions to represent the most probable saline constituents of the water. In the present state of our knowledge there are objections to both methods. Both are based on theories which are far from meeting with general acceptance. In this connection I may quote the following paragraphs from 'Ostwald on Solutions,' chapter vii. pp. 188–9. Referring to certain laws which have been found to be applicable for solutions of indifferent substances in various solvents, he shows that these do not apply to solutions of salts in water. He says: 'The behaviour of these substances is as if the solutions contained a considerably greater number of molecules of the dissolved substances than corresponds with their formulæ—i.e. as if the substances in solution were broken up into smaller molecules.

'The solutions which exhibit these deviations from the laws of vapour possess another characteristic peculiarity; they, and only they, are good conductors of the electric current, and they conduct electrolytically—i.e. the movement of electricity is accompanied by a movement of ponderable particles which are called "ions." By ions are understood the constituent parts of salts, acids, and bases, viz. on one side, the metals, the metal-like radicles such as $NH_4$ and hydrogen, and on the other side, the halogens, the acidic radicles such as $NO_3$ or $SO_4$, and hydroxyl. The positive electricity moves along with the first named, or positive, ions, while the negative electricity accompanies the second, or negative, ions. The consideration of these relations, along with the deviations from the laws of vapour-pressure, leads to the supposition that *in their aqueous solutions the substances in question*, i.e. *the electrolytes, are already separated for the most part into their ions*. This conclusion was arrived at by Arrhenius; the conclusion, it must be admitted, is, to some extent, opposed to the views which generally prevail, but it is in agreement with quite a remarkable number of facts.' This was written in 1891, and further researches have only tended to confirm the opinion of Arrhenius.

An analysis giving only the amount of the ions does not, however, appear to be very satisfactory, and conveys little information to the lay mind. It is advisable, therefore, always to give the probable combinations, by which are meant the salts most probably taken up by and dissolved in the water. This differs very little from the usual method of combining the ions in the order of insolubility of the salts formed by their combination. A Table in the Appendix contains a list of salts which may enter into solution in natural waters, in the order of their insolubility, as given by Bunsen in his 'Instruction für die Ausführung der vom Grossherzogl. Bad. Ministerium des Innern angeordneten chemischen Untersuchung der Badischen Mineralwasser.' The number of such salts found in ordinary potable waters is small, and I determine them in the following order:

1. $CaCO_3$
2. $CaSO_4$
3. $CaCl_2$
4. $Ca2(NO_3)$
5. $MgCO_3$
6. $MgSO_4$
7. $MgCl_2$
8. $Mg2(NO_3)$
9. $Na_2CO_3$
10. $Na_2SO_4$
11. $NaCl$
12. $NaNO_3$
13. $K_2SO_4$
14. $KCl$
15. $KNO_3$
16. $K_2CO_3$

This is not exactly in the order of insolubility, but in practice it works out more in accordance with the order of probability, and its simplicity appeals to me. As long as the actual determinations are given, other chemists may combine the ions as they please.

FACTORS FOR USE IN WATER ANALYSES

| Cations | Anions | Salt formed |
|---|---|---|
| 1 part Ca combines with | 1·5 $CO_3$ | 2·5 $CaCO_3$ |
| 1 ,, Mg ,, | 2·46 $CO_3$ | 3·46 $MgCO_3$ |
| 1 ,, Na ,, | 1·3 $CO_3$ | 2·3 $Na_2CO_3$ |
| 1 ,, Ca ,, | 1·772 Cl | 2·772 $CaCl_2$ |
| 1 ,, Mg ,, | 2·91 Cl | 3·91 $MgCl_2$ |
| 1 ,, K ,, | ·907 Cl | 1·907 KCl |
| 1 ,, Na ,, | 1·54 Cl | 2·54 NaCl |
| 1 ,, Ca ,, | 2·4 $SO_4$ | 3·4 $CaSO_4$ |
| 1 ,, Mg ,, | 3·94 $SO_4$ | 4·94 $MgSO_4$ |
| 1 ,, K ,, | 1·228 $SO_4$ | 2·228 $K_2SO_4$ |
| 1 ,, Na ,, | 2·083 $SO_4$ | 3·083 $Na_2SO_4$ |
| 1 ,, Ca ,, | 3·1 $NO_3$ | 4·1 $Ca2NO_3$ |
| 1 ,, Mg ,, | 5·1 $NO_3$ | 6·1 $Mg2NO_3$ |
| 1 ,, K ,, | 1·586 $NO_3$ | 2·586 $KNO_3$ |
| 1 ,, Na ,, | 2·69 $NO_3$ | 3·69 $NaNO_3$ |

Cl in $K_2PtCl_6$ × 0·368 = K contained in the double salt
Cl in $K_2PtCl_6$ × 0·701 = KCl contained in the double salt

The following examples will illustrate the mode of calculating the different constituents, and of recording the results.

### No. 1. CHALK WELL IN SOUTH ESSEX, FREE FROM ALL POSSIBILITY OF CONTAMINATION

IONS IN PARTS PER 100,000

| Cations | | Anions | |
|---|---|---|---|
| Ca | 7·5 | $CO_3$ | 12·0 |
| Mg | 1·2 | $SO_4$ | 3·4 |
| Na | 1·65 | Cl | 3·0 |
| K | ·55 | $NO_3$ | ·13 |

The 7·5 of Ca would combine with $7·5 \times 1·5 = 11·25$ $CO_3$, forming 18·75 $CaCO_3$.

The remaining $CO_3$, $12 - 11·25 = 0·75$, would combine with

$$\frac{0·75}{2·46} = 0·3 \text{ Mg, forming } 1·05\ MgCO_3.$$

The remainder of the Mg, $1·2 - 0·3 = 0·9$, would combine with

$$0·9 \times 3·94 = 0·3546\ SO_4, \text{ forming } 4·446\ MgSO_4.$$

or 3·4 $SO_4$ would combine with

$$\frac{3·4}{3·94} \text{ Mg} = 0·86, \text{ forming } 4·26\ MgSO_4.$$

The latter leaves 0·04 Mg uncombined, whilst the former shows that, to combine with the 0·9 Mg, the $SO_4$ required is 0·146 more than the $SO_4$ found in the water. With such trifling differences I give the mean of the two determinations:

$$(4·446 + 4·26) \div 2 = 4·35.$$

This brings the determination within 0·1 mlgr. per 100 c.c. of either result.

The Na would combine with $1·65 \times 1·54 = 2·54$ Cl, forming 4·19 NaCl.

The K would combine with the remaining Cl and the $NO_3$.

The water contained also 0·8 mlgr. $Fe_2O_3$ in suspension.

The total solids determined after evaporation, and drying at 180° C., weighed 31·7 mlgr., leaving 1·45 for silica, trace of organic matter, and errors.

The results are duly entered as shown on the following form:

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM CHALK WELL IN SOUTH ESSEX

EXPRESSED IN PARTS PER 100,000

| Ca 7·5 | Mg 1·2 | Na 1·65 | K ·55 | $CO_3$ 12·0 | $SO_4$ 3·4 | Cl 3·0 | $NO_3$ ·13 | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|
| 7·5 | — | — | — | 11·25 | — | — | — | Calcium carbonate . | 18·75 |
| — | ·3 | — | — | ·75 | — | — | — | Magnesium carbonate . | 1·05 |
| — | ·9 | — | — | — | 3·45 | — | — | ,, sulphate . | 4·35 |
| — | — | 1·65 | — | — | — | 2·55 | — | Sodium chloride . . | 4·20 |
| — | — | — | ·5 | — | — | ·45 | — | Potassium chloride . | ·95 |
| — | — | — | ·05 | — | — | — | ·10 | ,, nitrate . . | ·15 |
| — | — | — | — | — | — | — | — | Ferric oxide . . | ·80 |
| — | — | — | — | — | — | — | — | Traces ammonia, &c. . | 1·45 |
| Total solid constituents dried at 180° C. . . . . | | | | | | | | | 31·7 |

No. 2. The second example is an analysis of water from a chalk well, but in this case the well was sunk in a garden, and the effects of the manurial matter are shown by the presence of a large amount of nitrates.

WATER FROM CHALK WELL, SWANSCOMBE, KENT

IONS IN PARTS PER 100,000

| Cations | | Anions | |
|---|---|---|---|
| Ca | 14·05 | $CO_3$ | 16·5 |
| Mg | ·7 | $SO_4$ | 3·35 |
| K | ·6 | Cl | 5·0 |
| Na | 2·5 | $NO_3$ | 7·9 |
| | | $PO_4$ | traces |

The Ca here is obviously in excess of that required to combine with all the $CO_3$. The 16·5 parts of the latter would combine with $\frac{16{\cdot}5}{1{\cdot}5} = 11$ parts of Ca, forming 27·5 $CaCO_3$.

The remainder of the Ca is more than is required to combine with the whole of the $SO_4$.

The $SO_4$ will unite with $\frac{3{\cdot}35}{2{\cdot}4} = 1{\cdot}4$ of Ca, forming 4·75 $CaSO_4$.

The remaining Ca is not sufficient to take up all the Cl; it will combine with $[14·05 - 11·0 + 1·4] \times 1·772 = 2·9$ of Cl, forming 4·55 $CaCl_2$.

The Mg would combine with $0·7 \times 2·91 = 2·04$ Cl, forming 2·74 $MgCl_2$.

This leaves only $5 - 2·9 - 2·04 = 0·06$ mlgr. of Cl unaccounted for, a quantity so small as to be negligible.

The K will combine with $0·6 \times 1·586 = 0·95$ $NO_3$, forming 1·55 $KNO_3$, and the Na with $2·5 \times 2·69 = 6·7$ $NO_3$, forming 9·2 $NaNO_3$.

This accounts for $0·95 + 6·7 = 7·65$ $NO_3$, but as the Na is more likely to be underestimated than the $NO_3$ overestimated, it may be taken that the remainder of the $NO_3$ is combined with Na. Therefore, $7·9 - 0·95$ of $NO_3$ combines with

$$\frac{7·9 - 0·95}{2·69} = 2·6 \text{ Na, forming } 9·55 \text{ NaNO}_3.$$

The results are given on the Form below.

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM SHALLOW WELL IN CHALK, SWANSCOMBE, KENT

EXPRESSED IN PARTS PER 100,000

| Ca 14·05 | Mg ·7 | Na 2·5 | K ·6 | $CO_3$ 16·5 | $SO_4$ 3·35 | Cl 5·0 | $NO_3$ 7·9 | $PO_4$ *t* | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|---|
| 11·0 | — | — | — | 16·5 | — | — | — | — | Calcium carbonate . | 27·50 |
| 1·4 | — | — | — | — | 3·35 | — | — | — | ,, sulphate . | 4·75 |
| 1·65 | — | — | — | — | — | 2·9 | — | — | ,, chloride . | 4·55 |
| — | ·7 | — | — | — | — | 2·05 | — | — | Magnesium chloride . | 2·75 |
| — | — | 2·6 | — | — | — | — | 6·95 | — | Sodium nitrate . . | 9·55 |
| — | — | — | ·6 | — | — | — | ·95 | — | Potassium nitrate . | 1·55 |
| — | — | — | — | — | — | — | — | — | Traces of phosphates, organic matter, &c. | 3·25 |
| | | | | | | | | | Total solid constituents dried at 180° C. . . . | 53·9 |

No. 3. The third example is that of a typical water from the Thanet sands and chalk in central Essex. These waters contain the merest trace of potassium salts, and where the total saline constituents come within 2 mlgr. of the total solids I do not find

it necessary to determine the potassium and sodium. The ammonium often reaches 0·1 part per 100,000, and the silica 1 part.

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM CHALK UNDERLYING LONDON CLAY IN CENTRAL ESSEX

EXPRESSED IN PARTS PER 100,000

| Ca 1·4 | Mg ·5 | Na — | K t | $CO_3$ 24·0 | $SO_4$ 10·5 | Cl 42·4 | $NO_3$ ·2 | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|
| 1·4 | — | — | — | 2·1 | — | — | — | Calcium carbonate . . | 3·50 |
| — | ·5 | — | — | 1·25 | — | — | — | Magnesium carbonate . | 1·75 |
| — | — | 15·9 | — | 20·65 | — | — | — | Sodium carbonate . . | 36·55 |
| — | — | 5·05 | — | — | 10·5 | — | — | ,, sulphate . | 15·55 |
| — | — | 27·55 | — | — | — | 42·4 | — | ,, chloride . . | 69·95 |
| — | — | — | — | — | — | — | — | Traces nitrates, silica, ammonia, &c. . . | 1·20 |
| | | | | | | | | Total solid constituents dried at 180° C. . . . | 128·5 |

No. 4. The last example is that of a water from a shallow well forming the chief supply to a small town. The subsoil is highly polluted, and the water is loaded with nitrates, and contains large quantities of potassium salts. The amount of organic

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM PUBLIC WELL IN HIGH STREET

EXPRESSED IN PARTS PER 100,000

| Ca 14·8 | Mg 3·0 | Na 12·0 | K 8·8 | $CO_3$ 8·4 | $SO_4$ 26·5 | Cl 16·2 | $NO_3$ 26·4 | $PO_3$ *t.t.* | Probable combinations | |
|---|---|---|---|---|---|---|---|---|---|---|
| 5·6 | — | — | — | 8·4 | — | — | — | — | Calcium carbonate . | 14·0 |
| 9·2 | — | — | — | — | 22·1 | — | — | — | ,, sulphate . | 31·3 |
| — | 1·1 | — | — | — | 4·4 | — | — | — | Magnesium sulphate. | 5·5 |
| — | 1·9 | — | — | — | — | 5·5 | — | — | ,, chloride . | 7·4 |
| — | — | 7·0 | — | — | — | 10·7 | — | — | Sodium chloride . | 17·7 |
| — | — | 5·0 | — | — | — | — | 13·45 | — | ,, nitrate . . | 18·45 |
| — | — | — | 8·2 | — | — | — | 12·95 | — | Potassium nitrate . | 21·15 |
| — | — | — | — | — | — | — | — | — | Phosphates, organic matter, errors . | 4·8 |
| | | | | | | | | | Total solid constituents dried at 180° C. . . . | 120·3 |

matter is very small, and there are large traces of phosphates. In such waters the saline constituents, as directly determined, rarely come within 8 mlgr. of the total solids obtained by evaporation. The reason for this I have not yet ascertained.

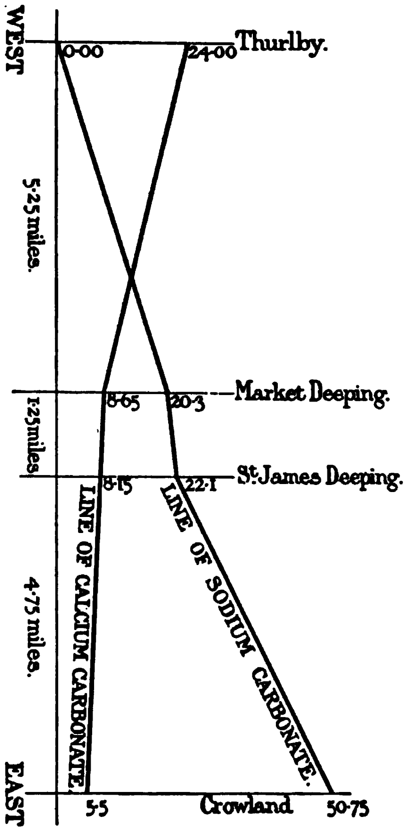

Fig. 11

At the end of this section I have recorded the results of a considerable number of analyses of waters from various sources made by the methods just described. Their study may possibly throw some light on geological problems, and stimulate inquiry for the purpose of ascertaining the causes of the difference in the character of underground waters. For example, certain of the waters are from the Lincolnshire limestone, and referring to these Mr. H. Preston, F.G.S., in 'Notes on the Geology and Underground Water Supply of South Lincolnshire,'[1] says 'that the series of analyses prepared by Dr. Thresh are of extreme interest, as they represent samples obtained from typical wells in the Lincolnshire limestone, from its normal condition on the west to its heavily charged condition on the east (as at Crowland) where the rock has thinned out. . . . One result deserves particular attention. The amount of dissolved calcium carbonate decreases from west to east, notwithstanding the longer travel of the water through the limestone rock, whilst the amount of sodium carbonate held in solution increases from east to west. This is shown in graphic form by the diagram' (Fig. 8).

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[1] **Paper read before the Annual Meeting of the Association of Waterworks Engineers, 1903.**

'Now, bearing in mind that the limestone decreases in thickness and becomes more argillaceous as it extends eastward, and that the upper and lower Esturine beds are coming closer together, and would probably meet at no great distance east of Crowland, the conclusions forced upon us are that, (1) the water contained in these beds is practically in a dormant condition, and as a consequence has been able to take up from the clay and adjoining beds increasing proportions of sodium carbonate, together with other soluble substances, and (2) that the sodium carbonate has precipitated corresponding amounts of calcium carbonate.'

I do not agree with Mr. Preston as to the source of the sodium carbonate. This salt occurs in waters from many different sources, and its origin I have been able to elucidate by the study of numerous analyses and by experiments which are recorded in the following paper on 'The Alkaline Waters of the London Basin,' which I recently contributed to the Essex Field Club:

In 1901 I published a report on 'The Water Supply of the County of Essex,' and included therein a map showing that to the east of a curved line passing from Dedham in the north to Barking in the south the waters derived from the chalk (save at the Purfleet outcrop) were 'soft' and contained more or less salt and sodium carbonate, whereas on the west of this line the waters had the ordinary character of chalk waters, that is, they contained very little salt and were free from sodium carbonate, but contained a considerable quantity of chalk in solution and were therefore 'hard.' It was also pointed out that in many localities the beds between the base of the London clay and the top of the chalk yielded waters containing an excessive amount of lime and magnesium salts, chiefly sulphates.

In the map above referred to, the dotted line is said to suggest a probable fault in the chalk. In some cases the marked difference in the character of the water, derived from wells not more than, perhaps, one mile apart, seems to indicate the presence of a fault; but there is no other evidence in support of this suggestion, and my further investigations lead me to conclude that it is not necessary to assume the presence of a fault to account for the facts observed.

All the observed results admit of another explanation. So long as the water in the chalk contains carbonic acid it continues to dissolve the chalk and open out the fissures. When all the acid has been used up in dissolving the calcium carbonate it no longer possesses the power of opening out the fissures, and as the chalk becomes more compressed by the superincumbent mass of sand and clay it becomes so dense as almost to be impervious. Beyond this point, therefore, the water cannot travel in the chalk, and it comes up through the fissured chalk into the sands above and then becomes exposed to their softening action. The compact chalk acts very much like a fault would do, assuming a solid impervious stratum abutting upon a previous one.

I do not purpose dwelling so much upon the geological aspect of the question as upon the varying character of the waters derived from the chalk and Thanet sands in different parts of the London basin, but more especially in Essex, and of offering an explanation for the variations in character.

The nature and progress of this change is well exemplified by the following analyses of waters taken from various wells sunk into the chalk at Eton, Datchet, Shepherd's Bush, the Strand, and Lambeth, London.

TABLE I

| Source | 1<br>Chalk.<br>Eton | 2<br>Chalk.<br>Datchet | 3<br>Chalk.<br>Datchet | 4<br>Chalk.<br>Shepherd's Bush | 5<br>Lon<br>Chalk.<br>Strand | 6<br>don<br>Chalk.<br>Lambeth |
|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 21·8 | 16·3 | 14·7 | 5·0 | 3·0 | 12·75 |
| Calicum Sulphate . . | 6·4 | — | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — |
| Magnesium Carbonate . | — | 3·6 | 3·1 | 3·5 | 2·1 | 7·85 |
| Magnesium Sulphate . . | — | — | — | — | — | — |
| Magnesium Chloride . . | 2·3 | — | — | — | — | — |
| Sodium Carbonate . . | — | 3·4 | 5·6 | 21·6 | 12·8 | 6·9 |
| Sodium Sulphate . . | — | 7·6 | 7·6 | 24·1 | 18·1 | 11·1 |
| Sodium Chloride . . | 1·1 | 5·8 | 5·6 | 22·6 | 18·2 | 14·4 |
| Sodium Nitrate . . | 3·5 | 1·3 | 1·2 | — | — | — |
| Silica, &c. . . . | 1·4 | 1·4 | 1·9 | ·6 | 1·2 | 1·0 |
| Total . . . | 36·5 | 39·4 | 39·7 | 77·4 | 55·4 | 54·0 |
| Hardness . . . | 30° | 22° | 18° | 8° | 5° | 20° |

Well No. 1 is on the outcrop of the chalk. The well (No. 2) at Datchet is nearer the chalk outcrop than well No. 3, and the latter therefore has a greater covering of London tertiaries. Wells No. 4 and 5 are bored through a considerable thickness of London clay. At Lambeth we are approaching the chalk outcrop in Kent and Surrey.

*Note* 1. The decrease in the calcium carbonate up to London and its increase towards Kent.
,, 2. The appearance of sodium carbonate and its increase towards London and decrease towards the Southern outcrop.
,, 3. The disappearance of calcium sulphate in the waters under the London clay.
,, 4. The appearance of sodium sulphate in the waters from under the London clay.
,, 5. The increase and decrease in the amount of sodium chloride.
,, 6. The whole series showing a marked change in the character of the chalk water as the distance from the outcrop of the chalk increases.

The next Table (II) of analyses includes typical samples of water taken in Essex along a line almost north and south from the bare chalk at Foxearth through Halstead, Bocking, Braintree, Witham, Chelmsford, and Billericay to Grays,[1] where the chalk again outcrops. Note again, the amount of calcium and magnesium salts in the chalk waters at and near the outcrop, the diminution of this amount as the chalk gets deeper, and the corresponding increase in the carbonate and sulphate of sodium, together with the increase in the amount of common salt.

TABLE II

| Source | Foxearth | Halstead | Bocking | Braintree | Witham | Billericay |
|---|---|---|---|---|---|---|
| Calcium Carbonate . | 31·0 | 25·3 | 21·9 | 5·3 | 2·8 | 1·8 |
| Calcium Sulphate . | — | — | — | — | — | — |
| Calcium Chloride . | — | — | — | — | — | — |
| Magnesium Carbonate . | — | 2·3 | 4·4 | 5·5 | 1·2 | 2·8 |
| Magnesium Sulphate . | 6·6 | 2·9 | — | — | — | — |
| Magnesium Chloride . | 1·6 | ·2 | — | — | — | — |
| Sodium Carbonate . | — | — | 3·1 | 19·8 | 26·7 | 26·3 |
| Sodium Sulphate . | — | — | 9·0 | 11·8 | 10·8 | 9·4 |
| Sodium Chloride . . | 4·5 | 14·0 | 28·0 | 67·2 | 78·3 | 36·5 |
| Sodium Nitrate . . | ·2 | ·4 | ·2 | ·2 | ·2 | ·2 |
| Silica, &c. . . . | 2·0 | ·9 | 1·0 | ·2 | ·5 | 1·0 |
| Total . . | 45·9 | 46·0 | 67·6 | 110·0 | 120·5 | 78·0 |
| Hardness . . . | 40° | 32° | 26° | 11° | 5° | 5° |

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[1] The analysis of Grays water will be found in Table VII., No. 6.

The Table shows, however, that whilst the carbonates and sulphates of sodium increase approximately in proportion to the decrease in the corresponding salts of magnesium and calcium, the amount of common salt seems to bear no relation to any of the other constituents. This is better brought out in Table III, which refers to a localised area which has recently had to be studied somewhat fully, viz., the Tendring Hundred, Mersea Island, and the Tollesbury districts. I have analyses of waters from about fifty deep wells in this area and the salt varies from 23 parts to 180 parts (or probably more) per 100,000, and it will be noted that some of the waters containing least salt are derived from wells near tidal estuaries, whilst many of the waters containing much salt are miles inland. The analyses of certain of the waters, however, indicate that tidal water is gaining access. This is well marked in the analysis of the Manningtree waters, No. 2, on Table III. The Geological Survey refers to wells at Ramsey, Pewit Island, Frinton, and other places which yielded brackish water and were apparently abandoned. Dr. Cook, Medical Officer of Health for the Tendring district, informs me that at Walton a well was bored and the water found to become more salt as the depth increased, the figures being:

At 100 feet. Salt per 100,000 parts of water 257 parts.
At 200 „ „ „ 258 „
At 300 „ „ „ 293 „
At 360 „ „ „ 308 „

A well sunk at Clacton gave me the results No. 3, on Table III. The yield of water was trifling, and upon continuous pumping the water became so brackish that it was abandoned. It will be noted that the water which rose naturally in the bore was comparatively soft, and contained sodium carbonate and no more salt than the deep well-waters of Mid-Essex. I am sorry that I did not obtain a sample of the water after continuous pumping, but the Engineer informed me that it was so salt that no analysis was necessary to show that it was too brackish for domestic use.

There is no doubt that in this area the water varies in character at different depths. The salt in the Walton water shows this, as does also the analysis of waters taken from borings recently made at Layer Marney, Nos. 4 and 5, on Table III. The yield at 568 feet was very limited, under 200 gallons per hour, and the boring was continued to 900 feet and blasts of dynamite used, but the yield of water was not materially increased and the proportion of salt increased to such an extent that the water was useless.

Layer Marney is so far from the sea that it appears difficult to ascribe this increase in the amount of salt to any direct influx of sea-water, but my impression is that sea-water or tidal-water is gaining access to the chalk in the Thorpe-le-Soken area, and at and near the chalk outcrop in the Stour Valley. The proof that these saline waters are derived from an admixture of sea-water and chalk-water is, I think, proved by the analyses of mixtures of chalk-water and sea-water after passing through a filtering medium which can remove the calcium and magnesium salts more or less completely, substituting sodium and potassium in their place. The mere proximity to the sea does not enable anyone to say whether a water will be salt or not, as a well near the coast may or may not contain an excessive amount of salt. For example, compare typical waters from Brightlingsea with those from Mersea Island and Tollesbury.

TABLE III

| Source | 1 10 per cent Sea-water | 2 Chalk Manningtree | 3 Chalk Clacton | 4 Layer 568 feet | 5 Marney 900 feet | 6 Mersea |
|---|---|---|---|---|---|---|
| Calcium Carbonate . | ·8 | 23·5 | 5·3 | 1·4 | 6·3 | 5·5 |
| Calcium Sulphate . | 13·3 | — | — | — | — | — |
| Calcium Chloride . | — | — | — | — | — | — |
| Magnesium Carbonate . | — | 6·5 | 4·2 | ·4 | 3·8 | 5·2 |
| Magnesium Sulphate . | 21·9 | 7·2 | — | — | — | — |
| Magnesium Chloride . | 36·7 | 1·8 | — | — | — | — |
| Sodium Carbonate . | — | — | 22·0 | 39·1 | 29·2 | 32·5 |
| Sodium Sulphate . | — | — | 16·1 | 12·7 | 12·4 | 22·9 |
| Sodium Chloride . . | 267·6 | 22·9 | 61·7 | 66·3 | 144·3 | 136·8 |
| Sodium Nitrate . . | — | ·2 | 2·6 | ·6 | — | — |
| Silica, &c. . . . | — | 2·7 | 2·6 | 1·5 | — | ·6 |
| Total . . | 357· | 64·8 | 114·5 | 122· | 196· | 203·5 |
| Hardness . . . . | abt. 100° | 45° | 11° | 2° | 11° | 12° |

I have made several experiments with mixtures of sea-water and chalk-water to show the effect of the softening process which I shall describe presently, and Table IV (see p. 356) is designed to show how the various waters in the London basin can be imitated by mixing chalk-water with sea-water and then submitting them to this peculiar treatment.

Varying proportions of chalk-water and sea-water were mixed, a portion reserved for analysis and the remainder filtered through Thanet sand of varying thickness and of varying activity so as to remove a portion or nearly the whole of the calcium and magnesium salts. It

TABLE IV

MIXTURES OF SEA-WATER AND CHALK-WATER

| Source | Untreated | Treated | Untreated | Treated | Untreated | Treated |
|---|---|---|---|---|---|---|
| Calcium Carbonate . | 12·7 | 2·0 | 25·2 | 1·0 | 24·3 | 3·8 |
| Calcium Sulphate . | 29·0 | — | — | — | — | — |
| Calcium Chloride . | 1·0 | — | — | — | — | — |
| Magnesium Carbonate . | — | 1·7 | 2·5 | ·5 | 3·4 | ·4 |
| Magnesium Sulphate . | — | — | 12·3 | — | 8·9 | — |
| Magnesium Chloride . | 10·3 | — | 6·6 | — | — | — |
| Sodium Carbonate . | — | 9·0 | — | 31·8 | — | 29·2 |
| Sodium Sulphate . | — | 30·3 | — | 16·3 | — | 15·6 |
| Sodium Chloride . | 103·5 | 118·8 | 113·1 | 126·2 | 72·0 | 73·0 |
| Sodium Nitrate . . | — | — | — | — | — | — |
| Silica, &c. . . | — | 3·2 | 1· | 2·2 | — | 2·0 |
| Total . . | 156·5 | 165·0 | 161· | 178· | 11·0 | 124· |
| Hardness . . . | 40° | 4° | 40° | 1½° | 33° | 5° |

will be observed that the lime and magnesium salts have been more or less completely removed and that the resulting filtrates are exactly of the type of the waters in the Tendring area as exemplified by the Tollesbury sample.

It would be difficult to regulate the rapidity of filtration or to vary the thickness of the filtering medium so as to remove exactly the right proportion of the salts of calcium and magnesium, but as we know that these can be removed to any desired extent the effect of the filtration can be easily calculated.

Table V shows how a mixture of 2 per cent. of sea-water with 98 per cent. of chalk-water from Halstead would be altered by filtration through different thicknesses of sand.

Braintree is about half-way between Halstead and Witham. Assume that the water in the chalk at Halstead becomes mixed with 2 per cent. of sea-water on its way to Braintree and at the same time is traversing the Thanet sands and becoming softened. Then the result at one stage would be the water (2) which, as will be seen, bears the closest possible resemblance to the Braintree water (3). Travelling onwards towards Witham the water would become still softer, more of the calcium and magnesium salts being removed, and at some point a water having the composition of No. 4 would result, and this, it will be noted, bears the closest resemblance to the Witham water No. 5.

Towards Chelmsford the water would become still softer, which is actually the case, but as the water in the Chelmsford area contains a little less salt we have to suppose that dilution with a less saline water is taking place, probably from the neighbourhood of Saffron Walden.

### TABLE V

### HALSTEAD CHALK-WATER + 2 PER CENT. SEA-WATER

| Source | 1<br>Untreated | 2<br>Treated | 3<br>Compare with Braintree | 4<br>Further treated | 5<br>Compare with Witham |
|---|---|---|---|---|---|
| Calcium Carbonate . | 27·3 | 5·3 | 5·3 | 2·8 | 2·8 |
| Calcium Sulphate . . | 1·8 | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — |
| Magnesium Carbonate . | — | 5·5 | 5·5 | 1·4 | 1·2 |
| Magnesium Sulphate . | 8·0 | — | — | — | — |
| Magnesium Chloride . | 9·8 | — | — | — | — |
| Sodium Carbonate . | — | 16·7 | 19·8 | 25·2 | 26·7 |
| Sodium Sulphate . . | — | 11·4 | 11·9 | 11·4 | 10·8 |
| Sodium Chloride . . | 63·3 | 75·2 | 67·2 | 75·2 | 78·3 |
| Sodium Nitrate . . | ·3 | ·3 | ·2 | ·2 | ·3 |
| Silica, &c. . . . | 1·0 | 1·1 | 1·2 | 1·3 | ·4 |
| Total . . | 111·5 | 115·5 | 111·1 | 117·5 | 120·5 |
| Hardness . . . | | 12° | 12° | 5° | 5° |

By varying the source of the chalk-water and the proportion of sea-water, I think every water from the chalk and Thanet sands in the county of Essex and under London could be imitated.

Assuming that the salinity is due to sea-water, then the bromides which exist in sea-water would be capable of detection in the saline waters. This proved to be the case, but when it came to the question of estimating the amount, great difficulties were encountered and have not yet been entirely surmounted. I give the following figures with some reluctance, but I think they can be depended upon for the purposes of comparisons.

### TABLE VI

### CHLORINE AND BROMINE IN SEA-WATER AND ESSEX DEEP CHALK-WATERS

| | Chlorine in 100,000 parts of Water | Ratio of Bromine to Chlorine |
|---|---|---|
| Sea Water, Clacton . . . . . | 1885 | 1 to 274 |
| [1] ,, Blackwater Estuary . . | 1850 | 1 to 328 |
| ,, ,, ,, . . | 1850 | 1 to 378 |
| Tollesbury Deep-well Water . . . | 75 | 1 to 225 |
| [1] Chelmsford ,, ,, . . | 35 | 1 to 250 |
| ,, ,, ,, . . . . | 35 | 1 to 322 |
| Maldon ,, ,, . . . . | 50 | 1 to 442 |
| Tillingham ,, ,, . . . . | 76 | 1 to 317 |
| Barking ,, ,, . . . . | 324 | 1 to 312 |

[1] Two separate determinations of each water showing variation in results due to difficulties in analysis.

The proportion of bromides to chlorides is therefore much the same as in sea-water, whether the saline water contains much salt, as the Barking water, or little salt, like the Chelmsford water.

The Barking water was especially selected, because there is no manner of doubt that tidal-water is entering the chalk here. From Grays to London, tidal-water is getting into the chalk at divers places, and frequently in such quantities as to render the water derived therefrom useless for manufacturing or domestic purposes. A further proof is the effect of pumping. The lower the water is reduced, the more and more closely does the water pumped resemble the tidal-water of the Thames in composition.

Moreover, cases are recorded of the rise and fall of the water-levels under tidal influence, as for example Thames Haven, where I am informed that the water in the bored-well rises and falls with the tide, and this is confirmed by the note in connection with this well in Whitaker's 'Geology of London.' Evidently in this locality there is some connection between the chalk and the river.

TABLE VII

CHALK-WATERS

| Source | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | | | | | Grays | |
| | Barking Town | Barking Creek, Well at | Barking Creek, Well at | Grays Thames Water | Heavy Pumping Chalk | No Pumping Well |
| Calcium Carbonate | 5·3 | 28·2 | 29·8 | 16·3 | 25·0 | 17·1 |
| Calcium Sulphate | — | 2·5 | — | 71·4 | 28·4 | 4·8 |
| Calcium Chloride | — | — | — | — | — | — |
| Magnesium Carbonate | 1·4 | — | — | — | — | — |
| Magnesium Sulphate | — | 7·4 | 13·1 | 129·5 | 8·8 | 1·6 |
| Magnesium Chloride | — | 18·6 | 9·9 | 154·8 | 24·6 | 1·7 |
| Sodium Carbonate | 14·9 | — | — | — | — | — |
| Sodium Sulphate | 9·9 | — | — | — | — | — |
| Sodium Chloride | 7·0 | 112·5 | 75·9 | 1411·6 | 140·4 | 2·6 |
| Sodium Nitrate | — | — | — | — | — | — |
| Silica, &c. | ·5 | ·8 | 1·3 | 70·4 | 15·8 | 4·2 |
| Total | 39· | 170· | 130·0 | 1854· | 243· | 32· |
| Hardness | 7° | 55° | 50° | 330° | 78° | 24° |

The Barking waters are very interesting (Table VII). Away from the river (1) they resemble the chalk-water of the Lee Valley partially altered by filtration through Thanet sand, but near the river they consist of a mixture of this chalk-derived water and river-water. Nos. 4 to 6 show the effect of the Thames water on the Grays wells when heavily pumped.

Table VIII shows the saline constituents of typical waters derived from deep wells in London. It will be observed that most of them are of the alkaline type, but that the proportions of the constituents vary. Nearly all indicate the admixture of a very small amount of sea-water with the chalk-water prior to it having undergone the softening process. Others derived from the chalk near the river show the presence of unchanged tidal-water, as at Millwall.

TABLE VIII

LONDON CHALK-WATERS

| Source | E.C. | Caledonian Road | Clement's Inn | King's Cross | Charing Cross | Millwall |
|---|---|---|---|---|---|---|
| Calcium Carbonate . | 4·4 | 4·0 | 4·4 | 3·4 | 4·0 | 27·6 |
| Calcium Sulphate . | — | — | — | — | — | 21·5 |
| Calcium Chloride . | — | — | — | — | — | 46·8 |
| Magnesium Carbonate . | 3·5 | 2·8 | 2·3 | 1·9 | 2·5 | — |
| Magnesium Sulphate . | — | — | — | — | — | — |
| Magnesium Chloride . | — | — | — | — | — | 15·2 |
| Sodium Carbonate . . | 18·0 | 19·1 | 21·4 | 21·8 | 18·4 | — |
| Sodium Sulphate . . | 20·1 | 20·0 | 23·2 | 21·9 | 24·8 | — |
| Sodium Chloride . . | 16·0 | 16·7 | 23·6 | 17·9 | 30·3 | 182·7 |
| Sodium Nitrate . . | ·3 | ·6 | ·2 | ·3 | ·3 | ·2 |
| Silica, &c. . . . | 1·0 | ·4 | ·4 | ·5 | 1·2 | ·2 |
| Total . . | 63·0 | 63·6 | 75·5 | 67·7 | 81·5 | 293·8 |
| Hardness . . . | 9° | 7° | 8° | 6° | 7° | 100° |

Table IX on p. 360 shows that so far away as Herne Bay the lower London tertiaries yield an alkaline water containing much sodium carbonate and sulphate, and other analyses on this Table and on Tables X and XI show that similar waters are obtainable from the most diverse geological formations. The examples given include waters from the Hastings Sands, Barton Sands, Upper and Middle Oolite, Ashdown Sands, Upper Greensand, Porphyrite and Calciferous Sandstone, New Red Sandstone, Millstone grit, Coal measures, Lincolnshire Limestone, and Table XI gives two examples of similar waters from

## TABLE IX

### VARIOUS SOURCES

| Source | Chalk. Herne Bay | Hastings Beds. Kent, Stye Place | Barton Beds. Cowes | Challow, Berkshire. Beneath Gault and K. Clay | | Swindon. Middle Oolite |
|---|---|---|---|---|---|---|
| Calcium Carbonate | 3·4 | ·4 | 14·7 | 6·2 | ·3 | 31·3 |
| Calcium Sulphate | — | — | — | — | — | — |
| Calcium Chloride | — | — | — | — | — | — |
| Magnesium Carbonate | 3·5 | ·2 | 3·7 | 2·6 | ·2 | 3·5 |
| Magnesium Sulphate | — | — | — | — | — | — |
| Magnesium Chloride | — | — | — | — | — | — |
| Sodium Carbonate | 23·0 | 65·2 | 1·4 | 41·4 | 73·9 | 14·0 |
| Sodium Sulphate | 41·7 | — | 5·6 | 8·6 | — | 48·3 |
| Sodium Chloride | 36·3 | 24·9 | 3·3 | 47·0 | 68·8 | 11·2 |
| Sodium Nitrate | ·2 | ·3 | ·4 | ·4 | ·4 | ·5 |
| Potassium Chloride | 5·6 | — | — | 5·6 | 8·4 | $K_2SO_4$14·4 |
| Silica, &c. | ·3 | 2·0 | ·4 | 2·7 | 2·0 | 4·3 |
| Total | 114· | 93·0 | 29·2 | 114·5 | 154· | 127·5 |
| Hardness | 8° | 1° | 19° | 10° | 1° | 35° |

## TABLE X

### VARIOUS SOURCES

| Source | Ashdown Sands. Tunbridge Wells | Skegness. Nr. Greensand or Thanet Sand | Kelso, N.B. Porphyrite | N.B.S. Warrington | M. Grit. Lancaster | M. Grit. Hallam |
|---|---|---|---|---|---|---|
| Calcium Carbonate | 2·25 | 2·6 | 1·3 | 8·7 | 14·0 | 3·0 |
| Calcium Sulphate | — | — | — | — | — | $BaCO_3$1·0 |
| Calcium Chloride | — | — | — | — | — | — |
| Magnesium Carbonate | 1·05 | ·7 | ·2 | 4·7 | 1·1 | 7·0 |
| Magnesium Sulphate | — | — | — | — | — | — |
| Magnesium Chloride | — | — | — | — | — | — |
| Sodium Carbonate | 12·0 | 27·6 | 25·2 | 3·0 | 1·8 | 13·6 |
| Sodium Sulphate | 5·2 | 4·0 | 2·0 | 3·1 | 2·8 | — |
| Sodium Chloride | 5·0 | 4·0 | 3·4 | 3·0 | 3·8 | 10·5 |
| Sodium Nitrate | ·3 | — | ·4 | 1·0 | ·2 | ·2 |
| Silica, &c. | ·2 | ·6 | 2·0 | ·7 | 1·8 | ·7 |
| Total | 26·0 | 39·5 | 34·5 | 24·2 | 25·5 | 36· |
| Hardness | 4° | 3½° | 2° | 14° | 16° | 13° |

TABLE XI

VARIOUS SOURCES

| Source | Coal Measures | | | Lincolnshire Limestone | | Damaraland. Micaceous Clay | Denmark Sands on Chalk |
|---|---|---|---|---|---|---|---|
| | Rochdale | Wolverhampton | Oldham | Nr. Peterboro | Peterboro | | |
| Calcium Carbonate . | 6·8 | 38·0 | 7·5 | 20·2 | 2·8 | 44·5 | 13·5 |
| Calcium Sulphate . | — | — | — | — | — | — | — |
| Calcium Chloride . | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 5·5 | 12·3 | 3·7 | 3·5 | ·9 | 38·4 | 1·0 |
| Magnesium Sulphate . | — | — | — | — | — | — | — |
| Magnesium Chloride . | — | — | — | — | — | — | — |
| Sodium Carbonate . | 7·6 | 9·4 | 9·7 | 5·1 | 55·5 | 9·7 | 19·0 |
| Sodium Sulphate . | 5·9 | 79·9 | 6·5 | 10·3 | 13·2 | 9·1 | ·3 |
| Sodium Chloride . . | 3·0 | 17·5 | 2·0 | 8·9 | 65·5 | 5·3 | 5·1 |
| Sodium Nitrate . . | 2·1 | — | 1·0 | ·4 | ·3 | — | — |
| Potassium Sulphate . | — | — | — | — | 4·6 | — | — |
| Silica, &c. . . . | ·7 | ·9 | 1·1 | 2·5 | 1·2 | 3·0 | 1·1 |
| Total . . | 31·6 | 158· | 31·5 | 50·9 | 144· | 110· | 40· |
| Hardness . . . | 14° | 53° | 12° | 26° | 4° | 90° | 15° |

Denmark, and Damaraland. In fact, these alkaline waters appear to occur in all parts of the world.

The question of the sources of the sodium salts is a problem at which I have been working for the last twenty years, and which has caused me to try numberless experiments. Last year, when referring to Bischof's 'Chemical and Physical Geology,' I came across a passage stating that a calcareous water passing through silicates of alumina containing potash and soda became softened, and directly afterwards I heard of a German process of softening water by filtration through an artificial zeolite, and the revivifying of the zeolite by treating it with brine. I tried an experiment with powdered soda glass, and I found that after soaking it in brine it had a slight softening effect. I next found that certain granites, without soaking in brine, had a marked softening effect, and that when this power was lost it could be restored by treatment with salt. The results[1] obtained with Mountsorrel granite were as follows:

EXPERIMENT 1.—Half a kilogram of granite dust was packed in a percolator and tap-water of 17° of hardness passed through. The hardness was not appreciably affected.

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[1] I have arranged my experiments in series commencing with granite. Each experiment quoted is merely typical of many others, which, as they simply confirmed the results given, do not require further mention.

Experiment 2.—Packed about 1 kilo. of coarse granite dust in the percolator and passed through water of 57° of hardness. The first 600 c.c. which passed through was very turbid. I collected successive 200 c.c. and estimated the hardness with the following results:

| | |
|---|---|
| 4th 200 c.c. . . . | Hardness 19° |
| 5th 200 c.c. . . . | Hardness 22½° |
| 6th 200 c.c. . . . | Hardness 28° |
| 7th 200 c.c. . . . | Hardness 30° |

Water ceased to pass through.

Experiment 3.—I now added a little dilute hydrochloric acid to the granite and stirred it up; water then passed slowly again. After the acidity had disappeared, water with 40° hardness was passed through and came out with only 2°, but the hardness rapidly increased and the water passed through very slowly. I then mixed the granite dust with brine. After soaking a few hours, the water passed fairly freely. Tap-water was passed through in successive half litres, and after the turbid point had been passed, to which I shall refer later, the hardness was estimated.

Original hardness of water, 17°.

Hardness of successive half litres: 5°, 0°, 0°, 0°, 0°, 1°, 2½°, 5°, 5° 5°, 5°.

Water of 40° hardness was now substituted. Results with successive half litres: 5°, 7°, 11°, 14°, 31°, 31°, 33°. The water ceased to pass, and the experiment was therefore stopped.

Experiment 4.—The granite was again soaked in brine, and it was found that the softening action was restored.

Different kinds of granite chippings and dust from the same quarries were tried with similar results; but the finer the material used, the more marked was the reaction obtained. A whiter granite has been since tried, but its softening effect was found to be comparatively slight.

The turbidity to which I referred above is due to the formation of a 'sol' or colloidal solution. It commences when nearly all the brine has passed through. The brine solution passes in a bright and colourless condition, and contains a good deal of lime and some magnesia in solution. Upon adding distilled water, until nearly all the brine has been washed through, the filtrate becomes very red and turbid. With the addition of more water the turbidity disappears, and if hard water is now passed through it comes out quite clear and softened.

About this time a boring was being made at Broomfield, near Chelmsford, and when the Thanet sand was reached I obtained some of it, but water would not pass through it when it was packed in a percolator. When shaken in water of 17° of hardness and filtered, the hardness of the water was reduced about 2°. Later, when pumping was in operation, a good deal of clean sand was brought up and deposited in the tank receiving the water. The following experiment was tried with this washed sand :

Experiment 5.—Packed about 200 grammes of the Broomfield sand in a cylinder and passed through it water of 57° hardness, collecting successive 100 c.c. Results : 54°, 20°, 8°, 7°, 11°, 16°. The sand was now so compact that more water would not pass through it.

*Note.*—Some expansion takes place in these experiments, as on three occasions experiments were stopped on account of the glass cylinders becoming fractured.

Obviously the sand had a softening effect.

Experiment 6.—More of the sand was collected and washed with tap-water to remove the clayey matter, and when put in a percolator it reduced the tap-water 2° in hardness. It was then soaked in brine and washed with distilled water. About 200 grammes used.

Towards the end of the washing, the liquid passing through the percolator became turbid and very similar to the turbid water which passed through the granite at the same stage. When this turbidity was disappearing, water of 60° hardness was passed through and successive 100 c.c. collected and examined. The results were : 4°, 8½°, 9°, 10°, 11°, 10°, 8½°, 12°, 17°, 20°, 20°.

Experiment 7.—Took a kilogram of the washed sand, treated it with brine and passed tap-water of 17° through in successive 200 c.c. Results : In the first five batches the hardness was 1° to 1·5°. Water of 60° was now passed through. The first fifteen batches had a hardness of 1·5°, the sixteenth and seventeenth of 2°. As all the hard water was used up, tap-water was used again. With fourteen successive 200 c.c. the hardness increased to 11°, and the fifteenth batch passed through unchanged. Altogether 7 litres of water were passed through.

Experiment 8.—The sand was again treated with brine and the tap-water passed through. The first three litres were completely softened, then the hardness increased gradually to 12° at the fourteenth litre. The fifteenth litre passed through unchanged.

The average hardness of the 14 litres was 5½°. One kilogram of sand therefore had removed lime (and magnesia) equivalent to 1·61 grammes of calcium carbonate. As will be seen later, the sand can remove more than this if a harder water is passed through.

Experiment 9.—The sand was next treated with acid, when it was found capable of removing more lime salt, but not nearly so much as when treated with brine. The acid and brine treatments were repeated, and the sand again salted and its lime-removing power tested. The total lime and magnesia removed corresponded to 2·09 grammes of calcium carbonate, indicating that the treatment which the sand had undergone had, if anything, increased its activity.

EXPERIMENT 10.—At the end of the above experiment more water of 57° was passed through, with the following extraordinary result. Successive half litres: Hardness 70°, 70°, 90°, showing that the sand was now giving up lime salts.

Unfortunately at this point my experiments had to be abandoned for a time, and the sand was inadvertently thrown away. Attempts to get a similar result again have so far failed.

EXPERIMENT 11.—From Heybridge, near Maldon, I was able to obtain some sand which was brought up by the pumps employed to try and clear a bored well. This sand allowed water to pass through freely and did not require washing. Through about half a kilogram a water of 20° of hardness was passed, and the successive 100 c.c. collected gave 2°, 2°, 2°, 2°, 2°, 4½°, 8°, 16°, 20° respectively.

Similar results were obtained with a sand from the new boring at Galleywood, near Chelmsford, but the sand had to be washed repeatedly with distilled water to remove the clayey matter before it would permit of water being filtered through it.

Thanet sand from several other places has been examined and in all cases it has exhibited the same power of softening water, to some extent after washing, and to a marked extent after salting. Some sand obtained for me from the outcrop close to Erith, by Mr. Barrow, of the Geological Survey, was found to contain a considerable quantity of lime salts, chiefly sulphate, and when water was passed through it, it increased the hardness enormously. After washing and salting it acted like the sand from deeper sources.

EXPERIMENT 12.—Thanet sand from a boring at Dedham, North Essex, contained much coarser quartz granules, but it would not let water pass through until the clayey matter had been washed away. When washed and salted it proved as active as any other sand examined. The amount of lime and magnesia removed corresponded to about 2 grammes per kilogram of the sand.

EXPERIMENT 13.—Through some salted sand from Thundersley, a mixture of sea-water and Halstead chalk-water was passed. The calcium and magnesium in the mixed water before and after treatment were estimated, with the following results:

| | Calcium | Magnesium | Hardness per 100 c.c. |
|---|---|---|---|
| Untreated . | 9·75 mlgr. . | 2·8 mlgr. . | 33 |
| Treated . | 1·5 „ . | 0·1 „ . | 5 |

These results indicate that magnesia salts are more readily removed than calcium salts.

**Experiment** 14.—Some natural water containing both salts being on hand, a quantity was passed through the same filter, with the following results:

| | Calcium | Magnesium | Hardness |
|---|---|---|---|
| Untreated | 6·75 | 3·65 | 34 |
| Treated | 4·4 | 0·75 | 14 |

again showing that a larger proportion of the magnesia salts was removed. This, however, does not appear always to be the case.

Recently I obtained a good quantity of Thanet sand from Dagenham (boring of the South Essex Water Co.), with which I made the following experiments:

**Experiment** 15.—Washed about 20 grammes of the original sand with distilled water until the hardness was only 4°; then agitated it with 100 c.c. of a water of 44° and syphoned off the water. The hardness had been reduced to 20°. Shaken with another 100 c.c. of the hard water, the hardness was reduced to 28°.

**Experiment** 16.—A quantity of the sand was washed with tap-water, then mixed with brine about the strength of sea-water and left exposed to the air for two or three days. The sand was then washed with distilled water, dried, and half a kilo. placed in percolator, and water of 130° hardness passed through. Successive 100 c.c. were collected. The hardness was decreased to 3°, but rose to 130 at the tenth 100 c.c. The amount of lime and magnesia removed, calculated as calcium carbonate, was 0·744 grammes or 1·5 grammes per kilo. of sand, or 0·15 per cent.

The sand before the hard water was passed through yielded 4·83 per cent. of the chlorides of sodium and potassium, and after the hard water had been passed through it yielded 4·61 per cent., a loss of 0·21 per cent. The amount of mixed chlorides represented by the 0·15 per cent. of lime salts removed is 0·208 per cent.

It is obvious, therefore, that only a small fraction of the sodium and potassium salts present in the sand takes part in this reaction.

**Experiment** 17.—The half kilo. of sand used in Experiment 16 was now salted with saturated brine, washed, &c. This time the washing water did not become turbid, but merely acquired a brown colour. Some calcium chloride was added to a very hard water and passed through the sand until no effect was produced on the hardness. Analyses gave the following results:

| | Calcium | Magnesium | Hardness |
|---|---|---|---|
| Untreated | 48·0 | 2·4 | 126 per 100,000 parts. |
| Treated | 19·1 | 1·4 | 52 „ „ „ |

As the amount of water passed through the sand was 2000 c.c., this half kilo. had removed 28·9 mlgr. calcium and 1·0 mlgr. magnesium per 100 c.c., equivalent to 1·52 grammes of calcium carbonate, from the whole of the 2 litres of water, or 3·04 grammes per kilo. of sand. Soaking with strong brine therefore had rendered the sand more efficient than soakage in brine of the strength of the sea-water.

Experiment 18.—The sand used in Experiment 17 was now washed with slightly dilute hydrochloric acid, then with distilled water and again salted. Hard water was passed through until it ceased to be affected. The reduction in hardness corresponded to the removal of 1·44 gramme of calcium carbonate or 2·88 grammes per kilo. of sand. The untreated sand only removed 3·04 grammes, so that the matter removed by dilute acid had no appreciable effect upon the softening.

Experiment 19.—The sand used above was soaked in strong hydrochloric acid, then washed, salted and washed free from salt. Upon passing hard water through it, the softening effect was very slight. The strong acid appeared to have removed the constituent to which the softening is due. The experiment has not been repeated or the result confirmed by using sand from other sources.

Experiment 20.—Some of the sand from Dagenham was lixiviated and divided into two portions, one the comparatively coarse sand and the other the finer portion, which would just permit of percolation of water through it. Equal quantities were treated with brine, washed with distilled water and then treated with successive 200 c.c. of hard water. The results were as under:

| | Calcium and Magnesium removed per kilo. of sand | | |
|---|---|---|---|
| Coarse sand. | | = 3·00 | grammes as calcium carbonate |
| Fine sand. | ,, ,, | = 2·74 | ,, |

Experiment 21.—Half a kilo. of Thanet sand unwashed from Galleywood boring softened 600 c.c. of water from 16° to 4°. It then became so compact that more water could not be passed through it. After washing and salting, 1 kilo. removed the equivalent of 4·08 grammes of calcium carbonate.

So far the results of my experiments indicate:

1. That the Thanet sand from beneath the London clay possesses the power of softening hard water, by substituting sodium (and possibly potassium) salts for those of calcium and magnesium.
2. That the constituent to which this softening effect is due is not removed by treatment of the sand with dilute acid, but appears to be removed by treatment with strong hydrochloric acid.
3. That this property of softening water belongs both to the clayey and sandy matters.
4. That the softening effect is greatly increased by treating the sand with brine.

5. That the amount of alkali removable by this softening effect is only a small proportion of the total alkalies contained in the sand.
6. That (within certain limits) a sand which has ceased to soften a water of a certain degree of hardness will exert a softening effect upon a water of a greater degree of hardness, and will exert a hardening effect upon a water of a softer character.

A few analyses of Thanet sands have been made in my laboratories, and the results obtained are compared with an analysis of a sample of granite dust, supplied to me, together with the analysis, by Messrs. Lavender and Bateman.

### TABLE XII

### COMPARISON OF GRANITE WITH THANET SAND

| | Granite | Thanet Sand (24) | Thundersley Sand |
|---|---|---|---|
| Silica | 67·16 | 86·55 | 83·74 |
| Alumina | 16·19 | 5·34 | 6·69 |
| Ferric Oxide | 3·82 | 2·24 | 2·30 |
| Lime | 2·59 | 0·85 | 1·78 |
| Magnesia | 1·58 | 0·40 | 0·68 |
| Potash | 5·38 | 2·13 | 1·48 |
| Soda | 2·43 | 0·77 | 1·29 |
| Water | 1·02 | 1·90 | 2·04 (*by diff.*) |
| | 100·17 | 100·18 | 100·0 |

A number of less complete analyses are given in Table XIII.

### TABLE XIII

| | Potassium and sodium expressed as chlorides | Per cent. soluble in dilute hydrochloric acid | Silica soluble in $Na_2CO_3$ after acid treatment | Insoluble residue |
|---|---|---|---|---|
| Granite | 11·5 | 10·2 | 3·4 | 86·4 |
| Dagenham Sand | 3·9 | 8·6 | 4·9 | 86·5 |
| Thundersley Sand | 4·7 | 7·8 | 2·3 | 89·9 |
| Dedham Sand | 4·2 | 7·1 | 4·4 | 88·5 |
| Dedham Sand (coarse) | — | 5·7 | 4·5 | 89·8 |
| Dedham Sand (clayey) | — | 14·8 | 3·2 | 82·0 |
| Thanet Sand No. 24 | 4·8 | 7·2 | 4·5 | 88·3 |
| Thanet Sand No. 140 | 4·5 | 6·8 | 6·0 | 87·2 |
| Thanet Sand No. 255 | 2·6 | 6·2 | 4·6 | 89·2 |

I am not competent to compare the mineralogical constituents of granite with those of the Thanet sands, and at present I merely direct attention to the fact that they have certain properties in common, which are probably due to a common constituent. Possibly some of the geologists present may be able to suggest what is the constituent. A sample of felspar (albite) has given disappointing results, and experiments have been commenced with mica. Whatever the constituent, it is certain that the alkaline carbonates and sulphates, found in the waters derived from the chalk and Thanet sands in the London basin, are obtained from the sands by substitution of sodium for calcium and magnesium in the sulphates and carbonates of calcium and magnesium present in the water before it commences to percolate through the sands. The analyses submitted show that every sample of such water can be imitated by passing a chalk-water either without admixture, or with an admixture of a small proportion of sea-water, through Thanet sand, which has retained its softening powers. If we assume, and such certainly appears to be the case, that the Thanet sands were deposited at the bottom of the sea, it is obvious that they would acquire the power to substitute sodium and potassium for the calcium and magnesium in any chalk-water with which they came in contact afterwards, and thus soften the water. If any salt remained in the sands, this would be taken up by the water, and the chlorides would be proportionately increased. In the districts in Essex and elsewhere, where these alkaline waters are found, there are localities where the amount of salt in the water is excessive ; and most of these, but not all, are near the coast or tidal rivers, and the question may arise whether the salt now found in such waters is derived from prior evaporation of the water from the original sea, or from sea-water getting into the chalk at various places at the present time. My impression is that it is due to an actual admixture of sea-water getting into the chalk and sands around the coast and in the Thames and Stour estuaries, and that this tidal-water gets more and more diluted with true chalk-water the farther it travels from these points. Thus in the Tendring Hundred most of the waters contain a comparatively large amount of salt, and farther away from this district the salt decreases. Towards the south of the county the chlorides are comparatively low, due to more copious admixture with water from the Hertfordshire chalk. I might mention that in all these areas the water derived from the chalk is practically identical with that derived from the Thanet sands : where there is any difference the salinity increases with the depth of the boring, e.g., Layer Marney and Walton-on-the-Naze. At Chelmsford and Braintree I have been able to get waters from the two sources, and found them practically identical. At Ingatestone there was no water whatever in the Thanet sands, but the limited amount obtained from the chalk was a typical alkaline water. These waters contain no free carbonic acid, therefore whatever distance they may travel in the chalk, no solution of the rock occurs; hence, however much of the water is pumped, the fissures do not enlarge and do not yield water more freely.

Engineers persist in continuing the borings made in Central Essex into the chalk, but there is no evidence of more water being obtained than would have been the case had the boring ended in the sands, whereas there is evidence that some of the sand-water is lost. Thus at Writtle a certain amount of water was obtained from the Thanet sands, and when the boring pierced the chalk most of the water disappeared and the chalk had to be plugged to restore the supply. At Tollesbury, where a deep bore has just been made, the water-level fell some 15 feet when the chalk was pierced, a sure indication of a loss of water. Experience elsewhere, which I am not at liberty to mention specifically, proves that the chalk absorbs rather than yields water in those areas where it is covered with a large thickness of London clay. In any case the waters have a common origin, and if the chlorides are derived from the sea they should be accompanied by bromides, and the amount should be approximately the same in proportion to the chlorides as in sea-water. In sea-water, as before stated, I find that there is one part of bromine to from 274 to 378 parts of chlorine, and that in the alkaline waters the proportions vary, there being for one part of bromine to from 225 to 412 parts of chlorine. Considering the difficulty of making anything like an accurate estimation of the bromine, these figures are sufficiently close to indicate some relationship. The difficulty of making an exact determination led me to abandon temporarily further determinations until I had worked out a process which could be relied upon. This has proved far more difficult than I had anticipated, and I am not yet so certain of my results as to feel justified in giving others. I suspect that in sea-water there are other compounds of bromine besides bromides, and that there are traces of iodides and iodates, or both. This, however, is a chemical question upon which I shall have something to say elsewhere.

Possibly it may be asked whether the softening effect of the Thanet sands is sufficient to account for the removal of nearly all the calcium and magnesium salts from the large volume of water taken from the sands. I think there can be no doubt about the answer. Taking Essex alone, the area under which Thanet sands exist must be about 666,000 acres, and assuming the average thickness to be 12 feet (a very low estimate), and that each cubic yard contains 28 gallons of water, the water held in the whole of the sand will be about 360,000,000,000 gallons. But my experiments indicate that each cubic yard would completely soften 10 cubic yards of a chalk-water 30° of hardness. The amount of water the Thanet sands are capable of softening on this basis is therefore 21,600,000,000,000 gallons.

Essex (Administrative County) has a population of over one million, and if liberally supplied with water it would use 30 million gallons per day or 10,950 million gallons per year. The amount of Thanet sand under the County would completely soften the whole supply on the above basis for 2000 years, and partially soften for a much longer period. I have recently obtained sandy matter from the beds resting upon the Thanet sand to ascertain if they have similar properties. Mr. Whitaker recognised this sand as being from the Blackheath beds. The sand contained much clayey matter, but it undoubtedly had the same action as the sand resting upon the chalk. The mineral or minerals which possess the power of softening water are probably very widely diffused, and no doubt are silicates of aluminium, calcium, and sodium of the nature of zeolites.

I have quoted this paper fully in the hope that some one may be sufficiently interested to follow up the experiments, or conduct experiments on similar lines to elucidate some of the problems relating to the origin of the constituents of underground waters. My results show that chemistry can, in certain cases, throw light also upon the direction of flow of such waters, but for this purpose the analyses must be much more full than those usually made for sanitary purposes.

Hitherto the estimation of the saline constituents of a water has been a difficult and tedious process, hence the paucity of such analyses. Now that sufficiently accurate, yet rapid and comparatively simple, processes have been devised, it is to be hoped that other chemists will make a special study of the peculiarities of waters from different geological sources.

## GRAVIMETRIC ANALYSIS OF THE SALINE CONSTITUENTS OF WATER

By far the most accurate system of analysis is that described by Bunsen[1] for use in examining the Baden Waters. It is excessively tedious, and could only be undertaken by a most expert chemist. The following account of an analysis of the Buxton

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[1] Bunsen, 'Instruction fur die Ausführung der vom Grossherzogl. Bad. Ministerium des Innern angeordneten chemischen Untersuchung der badischen Mineralwasser.'

Thermal Water, made by Bunsen's method, gives all the details necessary for the examination of waters generally, and shows the methods employed for calculating the probable errors of the determinations, for eliminating the errors, and for checking the results. The analysis was made by me in the year 1881, and required a large amount of time for its completion. By the methods used, however, the skilled chemist could undertake a similar analysis of any mineral water.

Without going into all the elaborate details described by Bunsen, and without examining separately the soluble and insoluble portions, the various ions can be determined gravimetrically and the results tabulated either by Bunsen's method or by the simpler one to which reference has already been made. In most cases the results, though taking much more time to obtain, will not be more valuable than those obtainable by the methods I have adopted, and which have just been described.

## CHEMICAL EXAMINATION OF THE BUXTON THERMAL WATER[1]

**Density of the Water.**—On account of the small amount of saline matter present in this mineral water, it was necessary to collect and evaporate large quantities of it. The water was collected in stoppered Winchesters.

A 50 c.c. specific gravity flask, filled with well-boiled distilled water, held, at 15° C., 49·9870 grammes, and at 14° C. 49·9954 grammes.

From equation—

$$C = \frac{w}{d}(1 - ta)$$

we have in both cases $C = 50{\cdot}029$ cubic centimetres at 0° C.

The flask filled with the spring water at 25·8° C. held in one experiment (1) 49·8890 grammes, in another (2) 49·8874 grammes.

| | |
|---|---|
| Density at 25·8° C. (1) | 0·99688 |
| (2) | 0·99684 |
| Mean | 0·99686 |

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[1] Communicated to the Chemical Society, January 17, 1882.

The density of pure water at this temperature being 0·99695 (Rossetti), we have 0·99992 as the density of the thermal waters, compared with that of pure water at the same temperature. As both the carbon dioxide and saline constituents tend to increase the density of a water, the presence of nitrogen in solution would appear to have a directly opposite effect.

### DETERMINATION OF THE SALINE CONSTITUENTS

21480·4 grammes of the water were evaporated in a platinum dish on the water bath to dryness, care being taken to avoid loss by spirting, access of dust, &c. The residue was kept for several hours on the water bath, and then treated with successive small quantities of cold water. The aqueous solution was passed through a filter into a stoppered Schuster's burette, avoiding splashing, and the insoluble portion finally transferred to the filter washed to 1/10,000, and dried at 100° C.

**Analysis of the Soluble Portion.**—(A) The fluid in the burette was divided into five accurately weighed portions.

(1) The sulphuric acid was estimated by precipitation with barium chloride, &c., the resulting barium sulphate being digested repeatedly with water acidulated with hydrochloric acid, until a constant weight was attained.

(2) In another portion the calcium and magnesium were determined—the magnesium in the ammonium oxalate precipitate, and the calcium in the precipitate produced by ammonium phosphate, being ascertained.

(3) In estimating the chlorine, the silver chloride was collected in a porcelain crucible, the filter paper through which the wash water was passed being burnt in a tared coil of platinum wire.

(4) In the fourth portion the sodium and potassium were determined. The boiling solution was precipitated with baryta water, evaporated to dryness in a platinum dish on the water bath, the residue exhausted with a small quantity of water and filtered. The excess of baryta was removed by repeated treatment with ammonia and

ammonium carbonate, evaporation and ignition. The ammonia-free solution was next concentrated and digested for two hours on the water bath with a little freshly precipitated mercuric oxide, evaporated to dryness, gently ignited, the residue exhausted with water, and the solution evaporated to dryness in a small platinum crucible, gently ignited and weighed.

The fused mass was next moistened with hydrochloric acid, dried and weighed. The weight was unaffected by this treatment.

The residue was dissolved in water, and the solution divided into three accurately weighed portions. In one the chlorine was estimated, in another the potassium and magnesium (after removal of the excess of platinum by hydrogen), and the third kept as a reserve.

(5) The fifth portion was reserved.

**Analysis of the Insoluble Portion.**—(B) In this portion the carbon dioxide, silica, sulphuric acid, barium sulphate, calcium, magnesium, iron, and manganese were estimated.

The Winchesters in which the water had been collected were rinsed with dilute hydrochloric acid, the rinsings transferred to the platinum dish in which the water had been evaporated, and evaporated to perfect dryness. In this residue the trace of silica was estimated, and the acid solution precipitated boiling by sodium carbonate, the ppt., after washing and drying, being added to the insoluble water residue. In the filtrate, the sulphuric acid and magnesia were determined. The carbon dioxide equivalent to the sulphuric acid was deducted from the amount of that substance found in (B), whilst the equivalent to the magnesia was added thereto.

**Estimation of the Carbon Dioxide.**—The dried residue (B) was transferred to a small flask fitted with bulb acid tube and a long calcium chloride tube, and the whole weighed. After all the gas had been liberated, the acid fluid was raised to the boiling-point, then allowed to become perfectly cold, and a very slow current of dry air, free from carbonic acid, aspirated through the apparatus, for about an hour. The heating and aspirating were repeated until a constant weight was attained.

**Silicic Acid, Barium Sulphate, and Organic Matter.**—The fluid remaining in the flask was evaporated to dryness, treated with acid passed through a filter, the impure silica exhausted with alcohol and ether, and the organic matter thus removed and estimated. The ignited silica was treated with warm, moderately concentrated solution of soda, when a residue consisting of barium sulphate remained, the weight and purity of which were duly ascertained. The filtrate from the silica was transferred to a weight-burette and divided into three portions.

In (1) the sulphuric acid was determined.

In (2) the iron, manganese, calcium, and magnesium were estimated. After oxidation, by boiling with a little bromine water, the iron (with trace of calcium phosphate, and possibly of alumina) was precipitated by ammonia, redissolved and reprecipitated. The impure $Fe_2O_3$ thus obtained was dissolved in acid, and upon addition of ammonium molybdate, gave a very slight ppt., indicating the presence of a trace of phosphate too minute for estimation.

The acidified filtrate, after concentration, was treated with ammonia and ammonium sulphide, and the precipitated manganese determined as $Mn_3O_4$.

The filtrate from the manganese precipitate was acidified, concentrated on water bath, the sulphur filtered out, and the calcium and magnesium determined as in the soluble portion.

## Total Estimation

10740·1 grammes of water were evaporated to dryness, and the residue treated at once with hydrochloric acid to separate *silica* and *barium sulphate*. The acid filtrate was divided into three portions, *a*, *b*, and *c*.

(*a*) In this portion the sulphuric acid was determined.

(*b*) Used for estimating the *iron*, *manganese*, *calcium*, and *magnesium*. The impure ferric oxide here obtained was dissolved in acid, the iron reduced to the ferrous state, and determined volumetrically by aid of a very dilute solution of permanganate of potassium.

In the ammonium oxalate precipitate traces of barium and strontium were found. The ignited oxide was treated with nitric acid, the dry nitrate digested with absolute alcohol, the solution filtered off, the minute residue washed with water, and the fluid evaporated to dryness. The barely perceptible residue was taken up on a strip of moist filter paper, and after burning the paper the ash was examined for barium and strontium by the spectroscope. Momentary indications were obtained of strontium, but the spectrum of barium was very distinct.

(*c*) Reserve.

For the estimation of the total *chlorine*, 3169·7 grammes were evaporated to dryness, and the solution obtained by exhausting the residue with water, precipitated with silver nitrate.

The total *alkalies* were determined in the residue, resulting from the evaporation of 8013·9 grammes of the water, the results being checked as in the former case by the estimation of the chlorine in the aliquot part of the mixed chlorides.

**Total Carbon Dioxide.**—The water used for this determination was collected in two flasks of about 1500 c.c. capacity, and each containing 50 c.c of a solution of one part of crystallised chloride of calcium in five parts of distilled water and ten parts of ammonia solution—Sp. gr. 0·96. This mixture had been made over two months, and was carefully filtered immediately before use. The flasks were fitted with doubly perforated stoppers. Through one opening was passed a short piece of glass tube, whilst the other was connected with a long tube, kept closed with the thumb whilst the flasks were being sunk in the tank into which the water was rising from the springs. Upon removing the thumb the water flowed into the flasks, and when the latter were full up to the bottom of the neck the thumb was again pressed on the end of the glass tube, and the flask withdrawn.

A mark being made on the necks of the flasks at the level of the liquid, the quantity used for the analysis was readily ascertained.

The flasks were kept on the water baths for several hours, then kept for more than an hour immersed in boiling water, and the clear fluid rapidly filtered off by aid of the filter pump. As much as possible of the precipitate was transferred to a small flask of about 150 c.c. capacity. The crystalline matter on the sides of the flasks was dissolved in dilute hydrochloric acid, reprecipitated boiling with slight excess of sodium carbonate, and the supernatant fluid filtered off. The precipitate was well washed, collected on the filter, and the latter with its contents transferred to the flask containing the remaining portion of the carbonates. The carbon dioxide was then liberated by hydrochloric acid, and after passing over calcium chloride and pumice with sulphate of copper, was absorbed in Geissler's bulbs containing solution of caustic soda, and attached to a soda lime tube.

In the filtrate from the sodium carbonate precipitate, the sulphuric acid and magnesia were estimated, and the requisite corrections afterwards made.

To detect and, if possible, estimate the fluorine, boracic acid, iodine, bromine, lithium, and other rare metals, 42,687 grammes of the water were evaporated to dryness, with addition of a little sodium carbonate. The residue was exhausted with hot water, and then with cold dilute hydrochloric acid, there being thus obtained (C) an aqueous solution, (D) an acid solution, and (E) a residue insoluble in dilute hydrochloric acid.

**Examination of (C).**—This measured 220 c.c., and was divided into three portions of 50, 50, and 120 c.c. respectively.

**Bromine and Iodine.**—50 c.c. were placed in a small stoppered bottle, and a little chloroform added after acidifying the fluid with hydrochloric acid. Standardised chlorine water was now dropped in, but not the slightest coloration was perceptible. For still greater certainty the solution was rendered alkaline with sodium carbonate, evaporated to dryness, gently ignited, and the residue dissolved in a small quantity of water, acidified, and filtered into a white dish. The chlorine water was now dropped into the heated fluid, but no indication of presence of either iodine or bromine was observable.

**Boracic Acid.**—To the second 50 c.c. were added magnesium chloride, ammonium chloride, and excess of ammonium carbonate, the mixture being evaporated to dryness, and the residue ignited. This was exhausted with hot water, and the filtrate submitted to a repetition of the above treatment. The two residues thus obtained were examined before the spectroscope for boracic acid, but with negative results.

**Cæsium, Rubidium, and Thallium.**—The filtrates from the residues obtained in searching for boracic acid, and the solution used in the examination for iodine and bromine, were evaporated to a small bulk, and precipitated with excess of platinic chloride. After twenty-four hours the clear fluid was poured off, and the residue boiled repeatedly with just sufficient water to cover it, the hot supernatant fluid being each time decanted. The whole of the ppt. ultimately dissolved, but from time to time portions were examined before the spectroscope, but no trace of these metals were found.

**Lithium.**—The remaining 122 c.c. were treated with excess of baryta water, then with ammonium carbonate, filtered, evaporated to dryness, and ignited. The residue was moistened with hydrochloric acid, dried, and exhausted with alcohol. The filtrate, upon evaporation, left a residue in which the spectroscope showed traces of lithium, but evidently the quantity was too small for estimation.

**Examination of (D).**—This solution, saturated with sulphuretted hydrogen, and kept in the hot-water oven for several weeks, deposited a fawn-coloured precipitate. This, when digested with ammonium sulphide, left a black-brown insoluble sulphide, and yielded a brown solution. The fluid was acidified with hydrochloric acid, and the precipitate fused with sodium carbonate and potassium nitrate, and examined for molybdenum, but with no decisive result. The insoluble sulphide proved to be lead, and was estimated as sulphate.

The filtrate from the hydric sulphide precipitate contained traces of iron, manganese, and calcium phosphate.

**Examination of** (E).—This residue was examined for fluorine, by fusion with four times its weight of sodium carbonate, exhausting the smelt with water, and freeing the solution from silica by digestion with ammonium carbonate. The filtrate was nearly neutralised with hydrochloric acid, calcium chloride added, and evaporated to dryness. The residue was washed with water after gentle ignition, dried, ignited, and weighed. After treatment with strong sulphuric acid and ignition, the fluoride of calcium was estimated from the increase in weight. The escaping vapour etched glass.

**Estimation of Ammonia and Nitric Acid.**—Upon attempting to estimate these substances by Bunsen's method, it was found that they were present in too small proportions for accurate measurement by his process. Half a litre of the water, therefore, was rendered slightly alkaline with sodium carbonate, and the ammonia in the distillate estimated with Nessler's solution in the usual way. After concentrating the water in the retort by evaporation to about 25 c.c., 15 grains of recently ignited pure caustic potash were introduced, together with six zinc-iron spirals. The tubulure of the retort was filled up to the contracted portion in its middle with moistened fragments of glass, and a glass tube, bent at right angles, and closed with a caoutchouc valve dipping into a little water, fitted to the end. After standing twenty hours, the retort was placed on the water bath for two hours, then 150 c.c. of water poured into it, and the ammonia distilled over and estimated.

Nitrous acid had previously been sought for, but not a trace could be detected.

From the mean values obtained as shown in Table C from the results of the 'total examination,' and of the analyses of the 'soluble' and 'insoluble' portions are calculated the most probable values of the products obtained in the latter. Let $A$ be the weight of any precipitate obtained on analysis of the portion soluble in water, calculated to parts in 10,000, and $B$ that of the precipitate from the insoluble portion, and $M$ the mean value of $A + B$ obtained as above. The portions $A_1$ and $B_1$ corresponding to this mean value are readily found from the equations:

$$A_1 = \frac{A}{A+B}M \qquad B_1 = \frac{B}{A+B}M$$

The values thus found are placed in the second column of Table D.

As a further control each of these numbers is divided by the *equivalent* weight of the substance as deduced from its chemical formula, and the product placed in Column III. In the soluble portion the sum of the numbers so obtained from the weights of the precipitates produced in estimating the acidulous radicals should correspond within the limits of experimental error with the sum of the numbers similarly calculated from the determination of the bases.

This concordance is not to be expected in the results from the insoluble portion, inasmuch as the silica exists in the water uncombined with any base. As also by continued evaporation the silicic acid may decompose a portion of the carbonates, the above method of control is not applicable. The sum total obtained by division of the quantities found in estimating the acids should, however, exceed that of the bases by a number somewhat less than that calculated for the silicic acid.

In calculating out the results of the analysis of the insoluble portion, a number is substituted in the fourth column for that of the carbonic acid in the third column of such magnitude as to render the sum of the values corresponding to the acids, less that of the silicic acid, equal to the sum found for the bases.

For calculating the results of the analysis of the soluble portion, let $A$ $B$ $C$ . . . be the equivalents of acid, Column III, Table D, and $A_1$ $B_1$ $C_1$ . . . the equivalents of base in the same column, s the sum of the former, and $s_1$ of the latter, then if $\frac{e}{a}$ be the probable error of such determination, we have

$$a\left(1+\frac{e}{a}\right)+b\left(1+\frac{e}{a}\right)+c\left(1+\frac{e}{a}\right)+\dots$$

$$=a_1\left(1-\frac{e}{a}\right)+b_1\left(1-\frac{e}{a}\right)+c_1\left(1-\frac{e}{a}\right)+\dots$$

consequently

$$\frac{e}{a}=\frac{s_1-s}{s_1+s}$$

By aid of the value of $\frac{e}{a}$ so obtained, are found the numbers in Column IV of the Table D, which numbers are employed for calculating the quantities of the various salts present in the water.

In a Table given by Bunsen, in the pamphlet previously mentioned, all the various salts found in mineral waters are arranged in the order of their decreasing solubility, and consequently in the order in which they would be deposited upon evaporation of a water holding all in solution.

In the soluble portion of the mineral water, the acids and bases are grouped in all the possible combinations, and the most difficultly soluble salt thus found is first estimated. In the present instance there are three acids and five bases, theoretically capable of combining to form fifteen different salts. Of these the least soluble is calcium sulphate, and

$$0{\cdot}000401 \times 68{\cdot}04\ (\tfrac{1}{2}CaSO_4) = 0{\cdot}027284 \text{ gramme}$$

represents the amount of this salt in 10,000 parts of the water.

The next in order of solubility is potassium sulphate :

$$0{\cdot}001018 \times 87{\cdot}19\ (\tfrac{1}{2}K_2SO_4) = 0{\cdot}088759 \text{ gramme,}$$

and, therefore, is the amount of this salt present.

The equivalent of sulphuric acid still available,

$$0{\cdot}003114 - (0{\cdot}000401 + 0{\cdot}001018) = 0{\cdot}001695,$$

is not sufficient to unite the whole of the sodium to form the salt next in order of solubility, hence

$$0{\cdot}001695 \times 71{\cdot}09\ (\tfrac{1}{2}Na_2SO_4) = 0{\cdot}1205 \text{ gramme}$$

represents the amount of sodium sulphate.

In a similar manner the remainder of the constituents are calculated.

The composition of the dissolved gases being, according to the mean of the result, given in a later section,

N 59·78 per cent. by volume
$CO_2$ 40·22 ,, ,,

the amount of nitrogen present has been calculated from that of the free carbonic acid, found in the water, by aid of this proportion.

The final result is tabulated in the usual form.

| | Parts in 10,000 of water |
|---|---|
| Calcium bicarbonate | 2·0014 |
| Magnesium bicarbonate | ·8587 |
| Ferrous bicarbonate | ·0044 |
| Manganous bicarbonate | ·0040 |
| Barium sulphate | ·0069 |
| Calcium sulphate | ·0273 |
| Potassium sulphate | ·0888 |
| Sodium sulphate | ·1205 |
| Lead sulphate | ·0006 |
| Sodium nitrate | ·0037 |
| Calcium fluoride | ·0028 |
| Sodium chloride | ·4412 |
| Ammonium chloride | ·0003 |
| Magnesium chloride | ·1361 |
| Silicic acid | ·1356 |
| Lithium | trace |
| Strontium | trace |
| Phosphoric acid | trace |
| Organic matter | ·0033 |
| Free carbon dioxide | ·0287 |
| Nitrogen | ·0272 |
| | 3·8915 |

## TABLE A

## TOTAL ESTIMATION IN GRAMS

| Quantity of Water employed | Product (with Impurities) | Weight of Solution | Portion of Solution weighed off | Precipitate obtained | Impurities in the Precipitate | Calculated for 10,000 parts of Water | |
|---|---|---|---|---|---|---|---|
| | | | | | | Impure Products | Impurities |
| 10740·1 | ·1508 $SiO_2$ | 81·522 | $SiO_2$, $MgO$, | $CaO$, $H_2SO_4$ | | | |
| | | | 14·854<br>18·3597 | ·0760 $BaSO_4$<br>·1932 $CaO$<br>·2137 $Mg_2P_2O_7$ | ·0064 $BaSO_4$<br>·0060 $Mg_2P_2O_7$<br>·0009 $CaO$ | ·14041 $SiO_2$<br>·38836 $BaSO_4$<br>·79873 $CaO$<br>·883497 $Mg_2P_2O_7$ | ·00596 $BaSO_4$<br>·02478 $Mg_2P_2O_7$<br>·00372 $CaO$ |
| 8013·9 | ·4969 $KCl + NaCl$ | 17·7770 | KCl and | NaCl | | | |
| | | | 6·6318<br>6·5376 | ·0737 $PtCl_4,2KCl$<br>·0012 $Mg_2P_2O_7$<br>·4384 $AgCl$<br>NaCl estimated (by diff.) | | ·24718 $PtCl_4,2KCl$<br>1·5109 $AgCl$ | ·00401 $Mg_2P_2O_7$ |
| 3169·7 | | | C | l. | | | |
| | | | | ·4789 $AgCl$ | | 1·5109 $AgCl$ | |
| 1526· | ·3197 $CO_2$ | | C | $O_2$ | | | |
| | | | | Filtrate from $Na_2CO_3$ ppt. gave | ·0015 $BaSO_4$<br>·0022 $Mg_2P_2O_7$ | 2·0950 $CO_2$ | 0·0098 $BaSO_4$<br>0·0144 $Mg_2P_2O_7$ |
| 996·9 | ·000011 $NH_3$<br>·000274 $HNO_3$ | | | | | ·00011 $NH_3$<br>·00275 $HNO_3$ | |
| 42687· | ·0121 $CaFl_2$<br>·0027 $PbSO_4$ | | | | | ·00283 $CaFl_2$<br>·00063 $PbSO_4$ | |

## TABLE B

## SOLUBLE AND INSOLUBLE PORTIONS

A. PORTION SOLUBLE IN WATER

| | PORTION WEIGHED OFF | PRODUCT WITH IMPURITIES | IMPURITIES | IMPURE PRODUCTS CALCULATED TO 10,000 PARTS OF WATER | IMPURITIES CALCULATED TO 10,000 PARTS OF WATER |
|---|---|---|---|---|---|
| Weight of Solution 109·1364 from 21480·4 grams water | 15·1814 | ·1078 $BaSO_4$ | | ·36078 $BaSO_4$ | |
| | 12·8082 | ·3772 AgCl | | 1·49629 AgCl | |
| | 28·9045 | ·0045 CaO<br>·0933 $Mg_2P_2O_7$ | ·0018 CaO | ·00798 CaO<br>·16400 $Mg_2P_2O_7$ | ·003192 CaO |
| | 35·3020 | ·4356 KCl + NaCl | Portion of solution employed=2769 0 gr. water<br>·0682 $PtCl_4,2KCl$<br>·0047 $Mg_2P_2O_7$ | ·62693 KCl + NaCl | ·2463 $PtCl_4,2KCl$<br>·01697 $Mg_2P_2O_7$ |
| B. PORTION INSOLUBLE IN WATER | | | | | |
| By action of hydrochloric acid . | | ·3103 $SiO_2$<br>1·9460 $CO_2$ | | ·14446 $SiO_2$<br>·90593 $CO_2$ | ·00778 $BaSO_4$ |
| Substance attached to dish and flasks | By action of HCl . | ·0003 $SiO_2$ | | ·00015 $SiO_2$ | |
| | Filtrate from $Na_2CO_3$ precipitate . . | ·0014 $BaSO_4$<br>·0012 $Mg_2P_2O_7$ | | ·00065 $BaSO_4$<br>·00055 $Mg_2P_2O_7$ | |
| | 32·9924 | ·0113 $BaSO_4$ | | ·01629 $BaSO_4$ | |
| Solution in acid, 102·1610 . . | 34·4675 | ·0016 $Fe_2O_3$<br>·0013 $Mn_3O_4$<br>·5796 CaO<br>·5048 $Mg_2P_2O_7$ | ·0386 $Mg_2P_2O_7$<br>·0017 CaO | ·79987 CaO<br>·69655 $Mg_2P_2O_7$ | ·05326<br>·00235 |

## TABLE C

## PRODUCTS FREE FROM IMPURITIES

CALCULATED AS OBTAINED FROM 10,000 GRAMS OF WATER

| | A<br>SOLUBLE PORTION | B<br>INSOLUBLE PORTION | A + B<br>TOTAL | TOTAL<br>ESTIMATION | MEAN |
|---|---|---|---|---|---|
| $SiO_2$ . . . . | | ·13668 | | ·13445 | ·13556 |
| $CO_2$ . . . . | | ·90593 | | 2·0990 | |
| $BaSO_4$ . . . . | ·36078 | ·01694 | ·37772 | ·38836 | ·38304 |
| AgCl . . . . | 1·49629 | | | 1·51090 | 1·50360 |
| $HNO_3$ . . . . | | | | ·00275 | |
| $CaFl_2$ . . . . | | | | ·00283 | |
| CaO . . . . | ·01117 | ·78303 | ·79420 | ·79352 | ·79386 |
| $Mg_2P_2O_7$ . . | ·15811 | ·74547 | ·90358 | ·90142 | ·90250 |
| NaCl . . . . | ·53708 | | | ·54092 | ·53900 |
| $(KCl)_2PtCl_4$ . . | ·24630 | | | ·24718 | ·24674 |
| $NH_3$ . . . . | | | | ·00011 | |
| $Fe_2O_3$ . . . . | | ·00221 | | ·00218 | ·00219 |
| $Mn_3O_4$ . . . . | | ·00179 | | ·00198 | ·00189 |
| $BaSO_4$ . . . . | | ·00778 | | ·00596 | ·00687 |
| $PbSO_4$ . . . . | | | | ·000633 | |
| $Al_2O_3$ . . . }<br>$Ca_3(PO_4)_2$ } . . | | | | ·000683 | |
| Organic matter . | | ·00275 | | ·00379 | |
| Lithium . . | | | | Trace | |
| Strontium . . | | Trace | | | |

## TABLE D

| I | II | III | IV | V | VI |
|---|---|---|---|---|---|
| **SOLUBLE PORTION** | | | | | |
| (1) *Estimation of Acids* | | | | | |
| $\frac{1}{2}$ $BaSO_4$ | ·86586 | ·0031867 | ·0136686<br>= s. | ·003114 | ·013570 |
| $AgCl$ | 1·50360 | ·0104883 | | ·010413 | |
| $HNO_3$ | ·00275 | ·0000436 | | ·000043 | |
| (2) *Estimation of Bases* | | | | | |
| $NaCl$ | ·53900 | ·0092121 | ·0134740<br>$= s_1$ | ·009278 | ·013570 |
| $\frac{1}{2}$ $PtCl_4$, $2KCl$ | ·24674 | ·0010111 | | ·001018 | |
| $\frac{1}{2}$ $CaO$ | ·01115 | ·0003986 | | ·000401 | |
| $\frac{1}{4}$ $Mg_2P_2O_7$ | ·15793 | ·0028457 | | ·002867 | |
| $NH_3$ | ·00011 | ·0000065 | | ·000006 | |
| **INSOLUBLE PORTION** | | | | | |
| (1) *Estimation of Acids* | | | | | |
| $\frac{1}{2}$ $BaSO_4$ | ·01718 | ·0001473 | ·0458878 | ·000147 | ·041469 |
| $\frac{1}{2}$ $SiO_2$ | ·13556 | ·0044887 | | | |
| $\frac{1}{2}$ $CO_2$ | ·90593 | ·0411790 | | ·041249 | |
| $\frac{1}{2}$ $CaFl_2$ | ·00284 | ·0000728 | | ·000078 | |
| (2) *Estimation of Bases* | | | | | |
| $\frac{1}{2}$ $CaO$ | ·78271 | ·0279437 | ·0414679 | 027944 | ·041469 |
| $\frac{1}{4}$ $Mg_2P_2O_7$ | ·74457 | ·0134158 | | ·013416 | |
| $\frac{1}{6}$ $Fe_2O_3$ | ·00219 | ·0000547 | | ·000055 | |
| $\frac{1}{6}$ $Mn_3O_4$ | ·00189 | ·0000495 | | ·000050 | |
| $\frac{1}{2}$ $PbSO_4$ | ·00063 | ·0000042 | | ·000004 | |

# CHAPTER XIV

## DETERMINATION OF THE GASES DISSOLVED IN WATER AND EVOLVED THEREFROM

In examining samples of water taken from different points along the course of a river, it is sometimes desirable to estimate the gases dissolved therein, more especially the dissolved oxygen. The more nearly the water is saturated with oxygen the better is supposed to be its quality and the more efficient the process of 'self-purification.' Recently the estimation of the dissolved oxygen has assumed greater importance as a test of the efficiency of the so-called bacteria beds in the purification of sewage. In this case the object is to produce a well-oxygenated effluent, such being found generally to be more satisfactory with regard both to the degree of purification and to its keeping properties, i.e. its non-liability to putrefactive change. At one time it was thought that the test might prove of service in differentiating between polluted and non-polluted waters, since a pure water kept in a full sealed flask retains its oxygen in a free state for an indefinite period, whereas a polluted water gradually loses its free oxygen, the gas being taken up by bacteria, or being otherwise used up in the oxidation of the organic matter. I made a large number of experiments in connection with this subject, simply to confirm the experience of others that the results were far from reliable and that the desired information could be more definitely obtained by the ordinary methods of chemical and bacteriological examination. The three gases which it may on occasions be desirable to estimate are oxygen, carbon dioxide, and nitrogen.

The two former can be estimated volumetrically by the methods about to be described, and if the total amount of dissolved gases be ascertained the difference may be ascribed to nitrogen[1] without any serious risk of error.

## THE GASES DISSOLVED IN WATER

### (a) ESTIMATION OF THE CARBON DIOXIDE

The total carbon dioxide, combined and free, can be estimated as described in the analysis of the gases in the Buxton water, and the combined acid having also been determined, the difference gives the free $CO_2$. Few will care, however, to adopt this process.

The method I adopt was described by Trillick, and gives very satisfactory results. Moreover, it requires no special apparatus and no special reagents. It depends on the fact that when a solution of barium hydrate is added to the water the free and the so-called semi-combined $CO_2$ combine with the barium hydrate, the insoluble barium carbonate being precipitated. Calcium carbonate being practically insoluble in water is precipitated when the $CO_2$ is removed, but magnesium carbonate not being so insoluble is converted into magnesium hydrate, and the other magnesium salts will also be decomposed in a similar manner. Sodium carbonate also precipitates with the barium hydrate, but insomuch as an equivalent of sodium hydrate is formed this does not interfere with the reaction. From the total $CO_2$ calculated from the loss of alkalinity, it is only necessary to subtract any due to the presence of magnesium salts, and the remainder represents the free and semi-combined $CO_2$ in the amount of water examined. It is assumed, therefore, that the Mg will have been determined.

The reagents required are: the standard solution of sulphuric acid, 1 c.c. = 2 mlgr. $CO_2$, a freshly titrated baryta water, and solution of barium chloride.

Into a flask capable of holding a little over 250 c.c., place 200 c.c. of the water to be examined, add 10 c.c. of the barium chloride solution, gently rotate, and after a few seconds add 40 c.c. of the baryta water. Close with a well-fitting stopper and again gently agitate until the mixture is uniform. Set aside all night or until the supernatant liquid is quite clear.

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[1] For estimation of argon and allied gases consult Traver's *Study of Gases* (Macmillan & Co.).

Remove with a pipette 100 c.c. of the clear liquid, add a little dilute phenolphthalein, and titrate with the standard acid (1 c.c. = 2 mlgr. $CO_2$). The amount of acid which would be required to neutralise the whole of the liquid is then calculated, and this, deducted from the amount required to neutralise 40 c.c. of the baryta water used, gives the loss due to the carbon dioxide and magnesium salts.

1 c.c. of the standard acid = 2 mlgr. $CO_3$ = 1·47 mlgr. $CO_2$.

1 mlgr. Mg corresponds to 1·83 mlgr. $CO_2$.

Let $x$ = the amount of free and semi-combined $CO_2$ in 100 c.c. of the water.

$a$ = the amount of Mg in 100 c.c. of the water.

$b$ = the no. of c.c. of acid required to neutralise 40 c.c. of the baryta water.

$c$ = the no. of c.c. required to neutralise the excess of baryta in the 200 c.c. of water,

then
$$1{\cdot}47\,\frac{b-c}{2} = x + 1{\cdot}83a,$$

whence
$$x = 0{\cdot}735\,(b - c) - 1{\cdot}83a.$$

The following is an example of such an analysis.

The baryta water employed was of such strength that 40 c.c. required 98 c.c. of the standard sulphuric acid for neutralisation. 200 c.c. of the water were taken and 100 c.c. of the clear supernatant mixture removed for titration. This required 30·4 c.c. of acid to neutralise the excess of barium hydrate. The water plus reagents amounting to 250 c.c. and 100 c.c. being taken for the analysis, the excess of alkali in the 100 c.c. multiplied by 2·5 gives the excess in the 200 c.c. of the water used. This gives 30·4 × 2·5 = 76·0 as the amount of acid necessary to neutralise the total excess of barium hydrate.

The free carbonic acid can be estimated by either of the following methods (1) and (2) or by both, (3) with sufficient accuracy for most practical purposes.

(1) To 100 c.c. of the water in a Nessler cylinder add 1 c.c. of neutral solution of phenolphthalein ($\overline{PT}$) and drop in from a burette $\frac{n}{10}$ solution of sodium carbonate until the least trace of pink becomes permanent. The tube should stand on a white tile and the best form of agitator is a glass rod with a round flattened and expanded end fitting easily in the tube. By raising and lowering the rod gently, instantaneous admixture is ensured.

(2) To 100 c.c. of the water add a drop or two of $\overline{PT}$ and 1 c.c. $\frac{n}{10}Na_2CO_3$ solution. Now titrate with $\frac{n}{10}HCl$ or $H_2SO_4$ until the last trace of colour has disappeared.

(3) Or proceed as in (1) and then run in excess of the carbonate solution to 1 or 2 c.c. and titrate back with acid as in (2).

In (1) the reaction is:

$$H_2O + CO_2 + Na_2CO_3 = 2HNaCO_3$$

and each c.c. of the volumetric solution corresponds to 2·2 mlgr. free $CO_2$.

In (2) the excess of sodium carbonate is determined, the red colour disappearing when the whole of the carbonate has become converted into bicarbonate.

$$2Na_2CO_3 + H_2SO_4 = 2NaHCO_3 + Na_2SO_4$$

1 c.c. of the acid solution therefore corresponds to 2 c.c. of the carbonate solution.

*Example* 1.—100 c.c. of a deep well-water required 0·35 c.c. $Na_2CO_3$ solution. One c.c. of the solution was added and the excess titrated with acid, 0·35 c.c. being required.

$$0{\cdot}35 \text{ c.c. } Na_2CO_3 = 0{\cdot}77 \text{ mlgr. } CO_2$$
$$1 - (2 \times 0{\cdot}35) = 0{\cdot}3 = 0{\cdot}66 \text{ mlgr. } CO_2$$
$$\text{Mean } 0{\cdot}71 \text{ mlgr. } CO_2 \text{ per } 100 \text{ c.c.}$$

*Example* 2.—A well-water required 1 c.c. of alkali to produce a pink tint, and a second c.c. was added. The excess required 0·5 c.c. acid to neutralise.

Both experiments therefore gave 2·2 mlgr. $CO_2$ per 100 c.c.

### (b) ESTIMATION OF THE DISSOLVED OXYGEN

The following method, devised by me in 1890 and first described in a communication to the Chemical Society in the following year, has been widely adopted, and its simplicity and accuracy cause it to be widely used.

It is based on the fact that a mere trace of nitrous acid will continue to liberate iodine in a solution of hydrogen iodide so long as air or oxygen has access to the solution.

The reaction is represented by the following equation:

$$2HI + 2HNO_2 = I_2 + 2H_2O + 2NO.$$

The liberated NO then acts as a carrier, more HI being decomposed, $2HI + O = H_2O + I_2$.

When the reaction takes place in a closed vessel it continues until all the free oxygen has been used up, and the amount of iodine set free corresponds to the amount of nitrous acid used, plus the amount of oxygen present. It is only necessary therefore to add a known quantity of sodium nitrite together with a little acid and potassium iodide to a definite volume of water, avoiding the presence of air, and to determine the amount of iodine liberated, in order to ascertain the amount of free oxygen in the water.

The reagents required are:

1. Solution of sodic nitrite and potassium iodide.
2. Dilute sulphuric acid (1 in 4).
3. Solution of starch.
4. Standard solution of sodium thiosulphate, 1 c.c. = 0·25 mlgr. O.

The apparatus required is shown in the accompanying figure.

A is a white glass bottle capable of holding about 500 c.c. closed by a caoutchouc stopper having four perforations. Through one passes the nozzle of a burette, C, through each of two others passes a short length of glass tubing bent at a right angle, and through the fourth the nozzle of a separating tube, D, which holds when completely full 252 c.c.[1] and has a mark on the neck at 250 c.c.

The bottle A having been thoroughly cleaned and dried, the tube D is filled carefully with the water to be examined up to the 250 mark, 1 c.c. of the nitrite solution is measured in by means of a pipette, and then 1 c.c. of the dilute acid. The stopper is now inserted, taking care not to include any bubble of gas. By gentle agitation mixture is effected, and after pushing the nozzle of the tube through the caoutchouc stopper it is allowed to

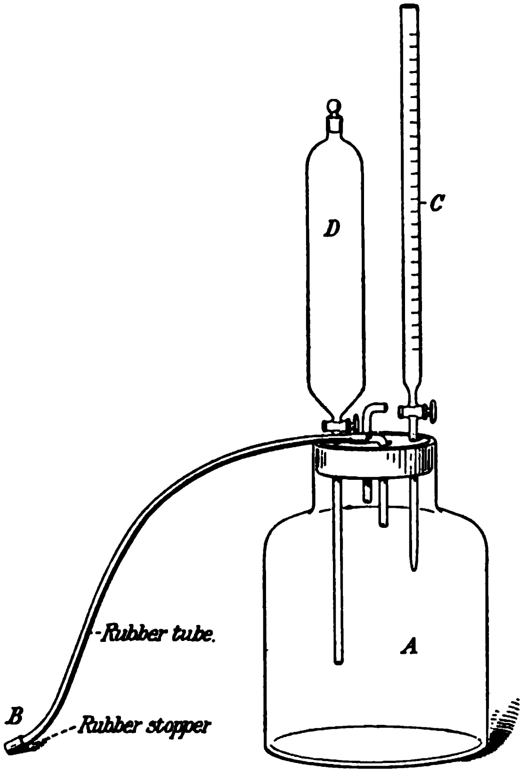

FIG. 12

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[1] The apparatus can be had from Gallenkamp & Co., Cross Street, Finsbury Square, and other instrument-makers.

remain at rest for fifteen minutes. The solutions of acid and nitrite should be delivered from the pipette, held vertically with its end under the surface of the water.

The burette filled with the thiosulphate solution is next placed in position (care must be taken to have the nozzle also filled), and one of the bent tubes having been connected with the gas supply, a current of gas is passed rapidly through the bottle until all the air has been expelled and the gas burns at B with a full luminous flame. The gas is then turned low, but a constant stream is kept up until the conclusion of the experiment.

The stopper of D is now removed and the cork B inserted. Upon turning the tap the liquid in D flows into the bottle. When D is empty, the cock is turned and the stopper reinserted. Thiosulphate is now run in until the colour of the iodine is nearly discharged. The stopper of D is again removed, 2 c.c. of starch solution poured in, and the tap turned to allow of this flowing into the bottle without the introduction of any air. The thiosulphate is again added until the blue colour disappears. The amount of thiosulphate used is then recorded. After the above determination is concluded, introduce into the bottle in succession 5 c.c. of nitrite solution, 5 c.c. of the acid and 10 c.c. of starch solution, and again run in the thiosulphate. One-fifth of the amount of thiosulphate thus used will correspond to the reagents used in the oxygen determination.

The thiosulphate should be well shaken before use, and it can then be regarded without appreciable error as being saturated with air, each c.c. containing oxygen equivalent to 0·031 c.c. of thiosulphate used.

Let $a$ = the amount of thiosulphate used by the water and reagents;

$b$ = the amount of thiosulphate corresponding to the reagents only;

$x$ = the amount of oxygen in one litre of the water;

then $x = 4 \times 0{\cdot}25\ [a - (b \times 0{\cdot}031\ a)]$.

$\therefore\ x = a - (b \times 0{\cdot}031a)$.

$\therefore\ x = 0{\cdot}969a - b$.

For example, 250 c.c. of spring-water gave the following results (temperature 14° C.):

$a = 9{\cdot}4$ c.c.
$b = 2{\cdot}1$ c.c.
$\therefore\ x = 9{\cdot}108 - 2{\cdot}1 = 7{\cdot}008$ mlgr. oxygen per litre, or 0·701 mlgr. per 100 c.c.

As 1 c.c. of oxygen at normal pressure and temperature weighs 1·42 mlgr., 100 c.c. of the water at 14° C. contained 0·494 c.c. of dissolved oxygen, measured at N.P.T.

At 15° C., 100 c.c. of water saturated with air contains 1·003 mlgr. oxygen, equal to 0·702 c.c. at N.P.T.

The above process is applicable to all potable waters. The very trifling amount of nitrites occasionally found has no appreciable effect. If desired, any nitrite present can be estimated, and the oxygen equivalent having been calculated, the correction may be made.

From the Table in the Appendix the percentage saturation can be calculated. Thus in the example above given, 100 c.c. of the water at 14° C. contained only 0·494 c.c. of oxygen, whereas had it been saturated, it would have contained 0·712 c.c., consequently the percentage saturation was $100 \times \frac{0{\cdot}494}{0{\cdot}712} = 69{\cdot}3$.

Another method devised by Winkler is still more simple and is accurate enough for most purposes.

The reagents required are:

1. A strong solution of manganous sulphate.
2. A solution of potassium iodide and sodium hydrate.
3. Sulphuric acid about 50 per cent. $H_2SO_4$.
4. Standard solution of sodium thiosulphate, about $\frac{n}{50}$.

All the apparatus required is a narrow-necked stoppered bottle of about 250 c.c. capacity: the exact capacity must be known.

This is filled with the water to be examined, taken with due precaution as described on page 398. The stopper is removed and 2 c.c. of the solution of manganous salt run in, followed by 2 c.c. of the alkaline iodide solution. If the tip of the pipette is placed beneath the surface of the water, no agitation with the air will occur. The stopper is now inserted and the contents of the bottle mixed. Set aside for a quarter of an hour, remove the stopper and add 2 c.c. of the sulphuric acid and agitate well until the precipitate caused by the alkali is dissolved. An amount of iodine is liberated equivalent to the amount of oxygen which was dissolved in the water, and is estimated by the thiosulphate in the usual manner, the contents of the bottle having been transferred to a larger flask.

*Example.*—Bottle holding 262 c.c. filled with water to be examined. After treatment, 13·9 c.c. of $\frac{n}{50}$ thiosulphate was required to decolourise the iodine liberated.

One c.c. thiosulphate = 2·54 mlgr. I = 16 mlgr. O, ∴ 13·9 c.c. thio. = 2·22 mlgr. O. This was contained in 262 − 4 = 258 c.c. of the water, ∴ 100 c.c. contained 0·86 mlgr. O $= \frac{0·86}{1·43} =$ 0·6 cubic centimetre. This is about the average amount found in Essex deep well-waters. A saturated water at ordinary temperatures contains about 1 c.c. oxygen per 100 c.c., but waters in which vegetation is active are often supersaturated, whilst very impure waters often contain much smaller quantities.

### (c) ESTIMATION OF THE TOTAL GASES

The water to be used for the estimation of the dissolved gases should be collected in boiling flasks of from half to one litre capacity. These are suitably weighted and sunk, and the water which at first enters, and has therefore been in contact with more or less compressed air, is withdrawn by means of a small pump or exhausting syringe connected with the flask by a length of rubber tube, weighted at the end if necessary by a piece of lead or tin pipe. The piston should be worked until the water removed measures four or five times the amount which the flask will contain. The flask is then withdrawn and a rubber stopper, perforated, inserted. Finally the perforation is closed by means of a short piece of glass rod, and the flask taken to the laboratory.

The apparatus employed in my laboratory for determining the amount of gases dissolved in water is illustrated in fig. 10; *a* is the flask containing the water, *b* a piece of narrow bore tubing, connected by a short length of stout caoutchouc tubing carrying a pinchcock, with the tubulure *b′* projecting from the glass-collecting vessel *c*. The second tubulure *d* is similarly connected by means of a caoutchouc tube, carrying a pinchcock, with a length of thermometer tubing, by means of which gas collected in *c* can be transferred to the eudiometer, or absorption tube, *g*. The open vessel, *e*, containing mercury, is connected with *c* by a length of stout rubber tubing.

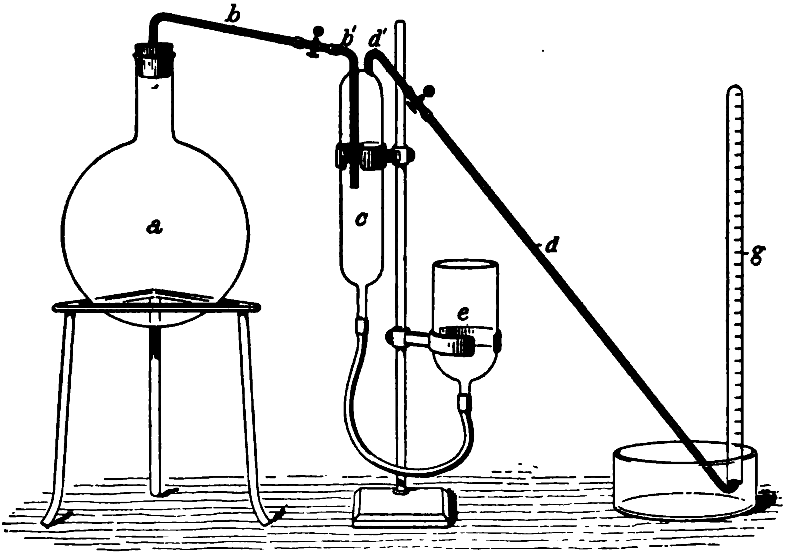

FIG. 13

When a determination is to be made, the flask filled with water is placed upon the stand, the vessel *e* lowered and filled with mercury. The pinchcocks on *b b′* and *d d′* are released, and *e* raised gradually until *c* and the tubes connected therewith are filled with mercury, care being taken to leave no air bubbles in the rubber tubing under the pinchcocks. The pinchcocks are then closed, and *e* lowered as far as possible and left in this position for some time, when, if no air bubbles have made their appearance, the experiment can be proceeded with. The free end of *b* is now inserted into the orifice in the stopper of the flask containing the water (care having been taken previously to replace any air or water in the cavity by mercury, and to see that the tube *b* is quite full of that metal), and gently pushed down so as to force the plug into the bottle, and until the end of the tube can just be seen below the stopper.

On now releasing the clamp upon *b b′*, lowering *e* and applying heat to the flask, the heat and diminished pressure cause the gas to be readily given off, and the water will boil at a temperature below 100°, depending of course upon the difference between the levels of the mercury in *c* and *e*. The expansion of the water causes a portion to pass into *c*, above which the evolved gas collects, and when the latter nearly half fills the tube, *e* is raised after opening the pinchcock on *d d′*, and most of the gas thus forced into the absorption-tube. This process can be repeated as often as necessary, care being taken not to force any mercury into the water flask, nor any water into the tube *d d′*, and to keep the end of the tube *b′* always under the surface of the fluid in *c*. Finally, by keeping *e* raised until the water is nearly at 100°, and then lowering, the water in *c* may be made to boil and give up almost the last trace of gas. On again raising *e*, &c., the whole of the evolved gas is collected in *g*, saturated with moisture, but, due precaution having been taken, without any trace of water on the surface of the mercury.

The capacity of *c* may vary according to the richness of the water in gaseous constituents, but will chiefly depend upon the quantity of water used, as when much gas is present it can readily be transferred from time to time into *g*. For flasks of from ½ to 1 litre capacity, *c* should be capable of holding at least 100 c.c.

The gas collected in the graduated tube must be measured, and reduced to N.P.T. It almost invariably consists of oxygen, nitrogen, and carbon dioxide. If the amount of the two former has been already ascertained, the amount of nitrogen is easily calculated. If desired, the mixed gases can be submitted to analysis.

### (*d*) ESTIMATION OF THE NITROGEN

The free and semi-combined $CO_2$ and the free O having been determined, and the total volume of gas liberated by boiling ascertained, the difference between the sum of the two former and of the latter may be taken as the amount of N present.

For example, in 100 c.c. of a given sample of water the free and semi-combined $CO_2$ amounted to 6·3 c.c. at N.P.T. and the O present was 0·5 c.c. The total amount of gas evolved from 490 c.c. of the water was 54·2 c.c. measured at 14° C. The barometer reading was 758 mm. and the mercury in the measuring tube was 175 mm. above the level of that in the trough. The tension of aqueous vapour at 14° C. being 11·9 mm., the pressure of the gas was $758 - 175 - 11{\cdot}9 = 571{\cdot}1$ mm.

Corrected to N.P.T., the volume of the gas evolved from 100 c.c. of water would be:

$$5{\cdot}24 \times \frac{571{\cdot}1}{760} \times \frac{273}{273 + 14} \times \frac{100}{490} = 7{\cdot}9.$$

The water therefore contained:

| | |
|---|---|
| Oxygen | ·5 c.c. |
| Nitrogen | 1·1 ,, |
| Carbon dioxide | 6·3 ,, |
| | 7·9 |

The following are a few examples of actual determinations:

GASEOUS CONSTITUENTS OF WATERS
BY VOLUME IN 100 C.C.

| — | Fresh rain-water | Limestone spring, Buxton | A pure river-water | River-water Sewage-polluted | Essex deep chalk |
|---|---|---|---|---|---|
| $CO_2$ | ·14 | 1·46 | 3·00 | 5·60 | 1·42[1] |
| O | ·64 | ·00 | ·75 | ·025 | ·61 |
| N | 1·30 | 2·21 | 1·50 | 1·51 | 1·29 |
| | 2·08 | 3·67 | 5·25 | 7·135 | 3·32 |

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[1] The whole existed in $CaCO_3$ $CO_2$ and $MgCO_3$ $CO_2$.

Whilst the free $CO_2$ and O are still frequently determined, the N is rarely estimated. At one time it was suggested that the ratio of the nitrogen to the oxygen was an index of the quality of the water, a pure water containing at least half as much oxygen as nitrogen, impure waters containing a smaller proportion of oxygen. This may be true of most river waters, but there are certainly numerous exceptions among spring waters, and consequently the determinations are but rarely made.

The gases evolved from water on boiling, and collected in the way above described, may be submitted to any of the ordinary processes of gas analysis for the determination of the constituents. The following is an example of such an analysis, and includes a description of the method adopted in examining the gases evolved from a spring.

### Gases dissolved in the Buxton Thermal Water

The flasks employed for collecting the water varied in capacity from 300 to 700 c.c. After being rinsed with the thermal water, a flask was weighted and sunk. A long piece of glass tube was attached at its upper end to a small pump or exhaust syringe, its lower end being inserted into the flask, and the water which had first entered the flask was displaced by the action of the pump. In this way samples of the water which had not been in contact with air and from the very bottom of the spring were collected. The above-mentioned tube was then withdrawn, and a rubber stopper inserted by aid of a long rod. The flask was then drawn to the surface. Great care had to be taken in these operations, as the slightest movement in the water caused a disengagement of gas bubbles.

The gas contained in the water was driven off in the apparatus already described, the boiling under diminished pressure being continued from one and a half to two hours. After collecting the evolved gas in an absorption tube, a bullet of fused KHO was inserted until all $CO_2$ and moisture had been removed. When the gas was afterwards treated with alkaline pyrogallate, a trace of oxygen was found, but from its small proportion and from considerations derived from the composition of the sinter, there could be no doubt that its presence was due to traces of air entering the apparatus during the analysis. The residual nitrogen was then measured. The carbon dioxide was determined in 100 c.c. and in 250 c.c. of the water in the following manner. The water was collected in pipettes of the above capacity by aid of a syringe, the pipettes being sunk as deeply as possible in the spring. The water was transferred to a flask containing (when 100 c.c. were used) 10 c.c. of a solution of ammonium chloride and calcium chloride (to precipitate the carbonates and to prevent the precipitation of magnesia) and 50 c.c. of lime-water of known strength added. After standing for twenty-four hours, 100 c.c. of the clear liquid were withdrawn and titrated with dilute nitric acid of such strength that 1 c.c. = 1 mlgr. $CO_2$. The precipitate of $CaCO_3$ was as far as possible collected on a filter, washed, and the filter and contents returned to the carefully rinsed flask. After treatment with a measured excess of dilute acid and gentle ebullition, the acid solution was titrated back with lime-water. This method answers very well when very little magnesium salt is present, but as a rule I now prefer the process previously described for determining the carbon dioxide. The above results enable us to estimate the nitrogen and the carbon dioxide, free and as bicarbonate.

The following is a typical result:

ESTIMATION OF THE NITROGEN

WATER TAKEN 707 C.C., TEMPERATURE 81·7° F.

| — | Volume | Pressure | Temperature | Volume at N.T.P. per litre of water |
|---|---|---|---|---|
| Residual gas after absorption of $CO_2$ . . . | 19·05 | 614·5 | 5° C. | — |
| After absorption of O . . | 18·80 | 614·9 | 2·9° | 21·3 |

Estimation of the total $CO_2$ in 100 c.c. This was found to be 0·1901 gramme..

The free and semi-combined $CO_2$ in 100 c.c. was 0·1096 gramme, and the difference between this and the total $CO_2$ gives the combined $CO_2$ = 0·0805. Then 0·1901 – 2(0·0805) = 0·0291, the free $CO_3$ corresponding to 14·72 c.c. per litre at N.P.T.

One litre of water therefore would contain:

| | | |
|---|---|---|
| N . . . . . . | 21·30 c.c. | = 59·13 per cent. |
| $CO_2$ . . . . . . | 14·72 ,, | = 40·87 ,, |
| O . . . . . . | trace | |
| | 36·02 | |

The mean of several determinations gave N 59·78 per cent., $CO_2$ 40·22 per cent. The composition of the gas which should be evolved from such a water is given by the equation:

$$\frac{100 \times 0{\cdot}01392 \times x}{0{\cdot}01392\, x \times 0{\cdot}9054\,(100 - x)} = 59{\cdot}78$$

where $x$ = per cent. of nitrogen and $100 - x$ the per cent. of carbon dioxide in the gas evolved, 0·01392 the solubility of nitrogen in water, and 0·9054 the solubility of carbon dioxide.

The theoretical and calculated compositions of the evolved gas are as under:

| | Theory | Found |
|---|---|---|
| N . . . . . . . | 98·98 | 99·12 |
| $CO_2$ . . . . . . | 1·02 | ·88 |

To charge pure water with the amount of gas found in the Buxton thermal spring would require a pressure of 1·64 atmosphere, the temperature of the water being 81·7° F. The origin of this nitrogen and the absence of oxygen have been the subject of much speculation, but the constitution of the sinter or deposit formed by the water explains both phenomena. The water at its source becomes charged with air under some little pressure, and afterwards traverses a bed of manganese ore capable of taking up oxygen; the whole of this gas is absorbed, the nitrogen alone remaining. The fact that the moist sinter from the water takes up oxygen when exposed to air is a proof of the absence of free oxygen in the water.

The composition of the mixture of gases given off naturally from an over-saturated water may be calculated from the proportions of the gases formed dissolved in the water, or may be directly determined as in the following experiment with the Buxton thermal water.

The gases were collected in flasks of about 100 c.c. capacity by means of a funnel inserted in the mouth. The flask was filled with the water of the spring, the funnel inserted, and the whole sunk and inverted in the spring. The bubbles of gas evolved ascended through the funnel, displacing the water in the flask. When full the mouth of each flask was closed with a caoutchouc stopper fitted with tubes, as figured in Bunsen's and Roscoe's 'Gasometry,' and then inverted in a glass cylinder containing sufficient water to cover the necks.

Arrived at the laboratory the gas was transferred as required to the absorption tube, and the $CO_2$ determined by absorption with balls of fused potash. The residual gas was inappreciably affected in volume by treatment with a papier-mâché ball impregnated with alkaline pyrogallate; it contained no combustible gas, and, in fact, comported itself in every way as pure nitrogen. (It has since been found to contain argon.) The analyses 1 and 2 were made from the same sample of gas. The pressures and volumes given refer to the dry gas. All readings were taken by aid of a telescope sliding on a vertical support.

| — | Volume | Pressure | Temperature |
|---|---|---|---|
| ANALYSIS 1 | | | |
| Gas taken | 43·01 | 693·9 | 8° C. |
| After absorption of $CO_2$ | 42·08 | 696·7 | 5·0° C. |
| Giving N | 99·161 p.c. | — | — |
| ,, $CO_2$ | ·839 p.c. | — | — |
| ANALYSIS 2 | | | |
| Gas taken | 42·28 | 687·8 | 5·9° C. |
| After absorption of $CO_2$ | 41·28 | 696·5 | 5·3° C. |
| Giving N | 99·083 p.c. | — | — |
| ,, $CO_2$ | ·917 p.c. | — | — |

The gas, if allowed to stand in contact with a little of the water, becomes richer in carbon dioxide, since the nitrogen and carbon dioxide dissolved in the water correspond to a pressure of 1·6 atmosphere and the proportion of carbon dioxide present is considerable; hence upon the removal of the pressure the evolved gas will become richer in carbon dioxide, and the greater the depth in the spring, the greater the pressure at which the gas is collected, and the less carbon dioxide will it contain. Analyses 3 and 4 are of gases which had stood for a time in a flask, in which by accident a little of the water had been left.

| — | Volume | Pressure | Temperature |
|---|---|---|---|
| ANALYSIS 3 | | | |
| Gas taken | 42·73 | 709·7 | 5·3° |
| After removal of $CO_2$ | 41·96 | 711·7 | 4·8° |
| ANALYSIS 4 | | | |
| Gas taken | 31·40 | 653·2 | 12·5° |
| After removal of $CO_2$ | 30·12 | 668·4 | 11·2° |

Giving (3) Nitrogen 98·65 per cent. and (4) 98·61 per cent.
,, $CO_2$ 1·35 ,, 1·39 ,,

The above-recorded experiments incidentally illustrate the precautions which have to be taken to obtain concordant results and explain why different results may be obtained from the same water.

Had the water contained any free oxygen, this would have been found in the evolved gases, and estimated from the loss in volume when treated with alkaline pyrogallate.

In making any future analysis of this character I should collect the gases in flasks, as above described, and transfer to a Hempel's gas burette, and absorb, first the carbon dioxide, and afterwards the oxygen in absorption pipettes. This method is more simple and, I think, less liable to error than Bunsen's.

# CHAPTER XV

## ANALYSIS OF THE SINTER DEPOSITED BY WATER

The examination of the sinter deposited by a water often throws some light upon its origin, or upon the nature of the strata which it traverses upon its way to the ground surface. Sinters are sometimes very simple in character, but in others they are exceedingly complex.

The rocks through the fissures of which the Buxton thermal water issues are coated with a dark brown mud. This mud or sinter was submitted to analysis to complete the examination of the spring. The analysis may be given as a sample of such an examination, but probably few sinters would be found of such a complex character.

This mud was collected by carefully scraping the slabs with a large knife. About as much as filled a 2–3 litre jar was obtained. Upon attempting to collect some from the bottom of the reservoir, the agitation caused it almost instantly to be diffused through the water, and carried away by the current.

A preliminary examination showed that this mud consisted chiefly of hydrated manganic oxides, with small quantities of iron, zinc, cobalt, calcium, barium, and magnesium, and carbonic acid, together with traces of molybdenum, lead, copper, aluminium, strontium, and phosphoric, silicic, and sulphuric acids. After washing with distilled water, and drying in a water oven, it shrank up very considerably, leaving an exceedingly light, purple-brown powder, which stained the skin when rubbed between the fingers. Instead of about a kilogram of dry residue being obtained, as expected, the weight of the whole, when dry, did not exceed 50 grammes.

Bunsen's, Marsh's, and other tests were applied for detection of arsenic and antimony, but no decided indication of the presence of either could be obtained.

As molybdenum, so far as I am aware, has never before been found in any mineral water, the proofs of its presence in this spring are given in detail.

For the qualitative examination a portion of the sinter was evaporated to dryness with hydrochloric acid and the residue treated with acid and water; a very small portion remained undissolved. The acid solution, when heated to 70° C. and perseveringly treated with hydrogen sulphide, yielded a red-brown, finely pulverulent precipitate, which required about thirty-six hours to settle.

This precipitate, when treated with potassium sulphide, partially dissolved, forming a reddish solution, which, upon addition of dilute hydrochloric acid, yielded a red-brown, flocculent precipitate. Portions of this, exposed on a thread of asbestos to the reducing flame of a Bunsen's lamp, gave a slight brown stain on the bottom of a porcelain dish held immediately over it, which stain was insoluble in ammonium hydrosulphide and sodium hypochlorite, but soluble in nitric acid. The remainder of the dry precipitate and the filter paper, mixed with a little sodium carbonate and nitrate, was added by degrees to fused sodium nitrate, and the melt treated first with water, then with alcohol. A trace only remained undissolved. The solution acidulated with hydrochloric acid gave with stannous chloride a brown coloration, and with potassium thiocyanate and zinc a rich crimson colour, unaffected by phosphoric acid, but taken up entirely by agitation with ether.

Another portion of the mud was exhausted with dilute nitric acid, and the acid solution was boiled with slight excess of sodium carbonate, and filtered. The concentrated filtrate gave with hydrochloric acid and stannous chloride, and with hydrochloric acid, potassium thiocyanate and zinc, the reactions of molybdic acid. After addition of ammonium hydrosulphide to this solution, excess of hydrochloric acid gave in a few minutes a distinct red-brown precipitate.

To render if possible the evidence still more complete, at the request of Professor Roscoe, to whom I was indebted for many valuable suggestions in the course of this investigation, an attempt was made to obtain the very characteristic compound of phosphoric and molybdic acids with ammonia, from the molybdic acid obtained in the quantitative analysis. This attempt was successful, for upon dissolving the oxide in nitric acid, adding a little ammonia, then again nitric acid in excess, the yellow precipitate referred to was produced in a few minutes upon adding a minute trace of sodium phosphate, and warming the solution.

In the ammonium hydrosulphide precipitate, insoluble in dilute hydrochloric acid, nickel was sought for, but not detected. The barium chloride obtained gave up to absolute alcohol a very minute portion, in which strontium could be detected by the spectroscope.

Hydrofluoric, tungstic, titanic, and boracic acids were specially tested for, but with negative results.

### QUANTITATIVE ANALYSIS OF MUD DRIED AT 120° C.

Loss on Ignition.—By ignition in a small table furnace, 0·7065 gramme lost 0·1143 gramme or 16·18 per cent.

0·5854 ignited over a blowpipe lost 0·097 gramme, or 16·57 per cent. Mean loss 16·38 per cent.

$CO_2$.—Estimated by aid of the apparatus used for a similar purpose and referred to in the analysis of the saline constituents of the water.

3·8955 gramme lost 0·1275 gramme of $CO_2$ or 3·27 per cent.

1·0631 gramme lost 0·0339 gramme of $CO_2$ or 3·20 per cent.

Mean 3·235 per cent.

$MnO_2$.—The oxide was determined indirectly by ebullition with strong hydrochloric acid, the evolved chlorine being caused to liberate its equivalent of iodine, which was estimated volumetrically with standard solution of sodium thiosulphate.

0·3388 gramme = 0·2587 gramme $MnO_2$, or 76·36 per cent.

0·3160 gramme = 0·2415 gramme $MnO_2$, or 76·42 per cent.
Mean 76·39 per cent.

Portion insoluble in hydrochloric acid. 20·1411 grammes, when treated with excess of hydrochloric acid, evaporated to perfect dryness on the water bath, then moistened with acid and treated with water, left a residue which after ignition weighed 0·2180 gramme = 1·08 per cent. This residue was not quantitatively examined, but consisted of barium sulphate, fine sandy particles, &c. ($SiO_2$, $Fe_2O_3$, $Al_2O_3$, $BaSO_4$).

PbO.—In the hydrogen sulphide precipitate, after treatment with potassium hydrosulphide until it was no longer coloured, the lead was estimated as sulphate by dissolving the residue in nitric acid, evaporating with sulphuric acid, washing with acidulated water, then with alcohol, drying, &c.

The lead sulphate weighed 0·0402 gramme, corresponding to 0·147 per cent. PbO, and, after treatment with potassium chromate, was entirely soluble in caustic potash.

CuO.—From the concentrated filtrate from the lead precipitate the copper was deposited on a platinum dish by the action of pure zinc. The copper obtained weighed 0·011 gramme, corresponding to 0·068 per cent. cupric oxide.

$MoO_3$.—Upon adding dilute hydrochloric acid to the potassium hydrosulphide solution, a reddish precipitate fell which was dried upon a small filter. The paper was cut up and mixed with sodium carbonate and nitrate, and gradually added to fused sodium nitrate. The filtered aqueous solution of the smelt, after being neutralised with nitric acid, the carbon dioxide having been allowed to escape, was precipitated by mercurous nitrate, and the precipitate after some hours was collected, washed with solution of mercurous nitrate, dried, and ignited in a porcelain boat in a current of hydrogen.

The resulting $MoO_2$ weighed 0·0003 gramme = 0·016 per cent. $MoO_3$.

$P_2O_5$.—After removal of hydrogen sulphide by evaporation from a portion of the solution which had been treated with that reagent, and corresponding to 1·7 gramme deposit, excess of ammonia was added, then nitric acid in excess and some ammonium molybdate. The resulting precipitate, after many hours, was collected and treated with ammonia and magnesium mixture in the usual manner. The magnesium pyrophosphate obtained only weighed 0·0026 gramme = 0·01 per cent.

CoO.—To a portion of solution corresponding to 3·247 grammes of dry mud, ammonium chloride, ammonia, and slightly yellow ammonium hydrosulphide were added in sufficient excess. After standing for twenty-four hours, the clear yellowish fluid was filtered off, and the precipitate rapidly washed with water containing a little ammonium hydrosulphide. In this precipitate the iron, aluminium, cobalt, and zinc were determined.

To isolate the cobalt, the precipitate was diffused through very dilute hydrochloric acid, and the mixture saturated with hydrogen sulphide. After filtering out the cobalt sulphide, the solution was reprecipitated by ammonia and ammonium hydrosulphide, and the precipitate again treated with dilute acid. The insoluble residue was digested with aqua regia (a minute portion, 0·002 gramme, of barium sulphate was found here and estimated), evaporated to dryness in a porcelain dish, then boiled with slight excess of potash in a platinum vessel, and the well-washed precipitate was strongly ignited. Its weight was 0·0103 gramme, corresponding to 0·3 per cent. CoO. The traces of $Fe_2O_3$ and alkali in this precipitate were not determined.

$Fe_2O_3$ and $Al_2O_3$.—The filtrate from the cobalt sulphide was boiled with a little nitric acid, filtered, nearly neutralised with sodium carbonate, and the mixed ferric oxide and alumina were thrown down by ebullition with excess of $NaC_2H_3O_2$ solution. The slightly washed precipitate was redissolved, reprecipitated, ignited, and weighed. The oxides, of which only a trace consisted of alumina, weighed 0·0440 gramme = 1·36 per cent.

ZnO.—The filtrates from the iron precipitate, acidulated further with acetic acid and saturated with hydrogen sulphide, gave a nearly white precipitate of ZnS, which was collected, and dissolved in dilute hydrochloric acid; the solution was mixed with a slight excess first of sodium carbonate, then of acetic acid, and the zinc sulphide was reprecipitated. When converted into zinc oxide by strong ignition in an open crucible, it weighed 0·0150 gramme = 0·462 per cent.

MnO.—On account of accidental loss of some of the solution, the manganous oxide had to be determined from a fresh portion of the deposit, after removal of the oxides of lead, copper, cobalt, and zinc, and of the ferric oxide, alumina, baryta, lime, and magnesia. The manganese was precipitated by ammonia and ammonium hydrosulphide, washed, dried, and ignited in a current of hydrogen. From 0·9061 gramme deposit, 0·7316 gramme manganous sulphide was obtained, corresponding to 66·19 per cent. MnO, or 71·11 per cent. $Mn_3O_4$. From estimation of $MnO_2$ the amount of oxygen united with the manganese over and above that required to form MnO is found to be 14·13 per cent., or 9·21 per cent. more than would convert the whole into $Mn_3O_4$.

Water of Hydration.—Found by deducting from the total loss upon ignition, the amount of $CO_2$ and O which would be driven off—

$$16{\cdot}38 - (9{\cdot}21 + 3{\cdot}24) = 3{\cdot}93 \text{ per cent.}$$

BaO.—The solution obtained by filtering off the precipitate produced by the addition of ammonium sulphide to the original solution was boiled with hydrochloric acid, filtered, rendered slightly alkaline with ammonia, and the calcium, barium, and trace of strontium thrown down by addition of ammonium oxalate to the hot solution. After reprecipitation and intense ignition, the mixed oxides weighed 0·1969 gramme.

This residue, after treatment with nitric acid and evaporation to dryness, was digested with absolute alcohol. After twenty-four hours, the thick liquid was filtered off and the residue washed with more alcohol, then dissolved in water, evaporated to dryness in a platinum dish, and weighed. Its weight was 0·0416 gramme, corresponding to 0·788 per cent. BaO (corrected for $BaSO_4$ found in CoS precipitate).

CaO.—Deducting the amount of BaO corresponding to 0·416 gramme $Ba(NO_3)_2$, we have 0·1725 gramme CaO = 5·31 per cent.

MgO.—The filtrate from the calcium and barium precipitates was evaporated to dryness, gently ignited, and the magnesia determined after reprecipitation as $Mg_2P_2O_7$. This salt weighed 0·2864 gramme = 3·178 per cent. MgO.

The results of the analysis are tabulated below, expressed to the nearest second decimal:

| | |
|---|---|
| $Mn_3O_4$ | 71·11 |
| O | 9·21 |
| $BaSO_4$ and other matters insoluble in HCl | 1·08 |
| PbO | 0·15 |
| CuO | 0·07 |
| $MoO_3$ | 0·02 |
| CoO | 0·30 |
| $Fe_2O_3 + Al_2O_3$ | 1·36 |
| ZnO | 0·46 |
| BaO | 0·79 |
| CaO | 5·31 |
| SrO | a trace |
| MgO | 3·18 |
| $CO_2$ | 3·23 |
| $P_2O_5$ | 0·01 |
| $H_2O$ | 3·93 |
| | 100·21 |

It will be noticed that this deposit corresponds closely in composition with that of many samples of psilomelane, and wad or bog manganese.

# CHAPTER XVI

## EXAMINATIONS FOR SPECIAL PURPOSES

### FOR ASCERTAINING THE AMOUNT OF CHEMICALS REQUIRED FOR SOFTENING PURPOSES

In all cases where a water is to be submitted to a softening process the saline constituents should be determined. When this is done it is a simple matter to calculate the amount of lime or of lime and sodium carbonate theoretically necessary to completely soften. Unfortunately, theory and practice often disagree. The carbonates of calcium and magnesium and magnesium hydrate are all slightly soluble in water, but the solubility varies with the temperature of the water and with the nature and amount of the saline constituents, and, apparently, to obtain the most complete softening effect an excess of reagent has to be added.

Judging from experimental softening results, obtained with waters at ordinary temperatures, a softened water may retain in solution 0·5 to 1·0 part of magnesium hydrate, and 1 to 1·5 parts of calcium carbonate in 100,000, but if a slight excess of lime is used this solubility is possibly decreased. When heat is employed in the softening process the magnesium carbonate or hydrate remaining in solution may be reduced considerably.

Gmelin (' Dictionary of Chemistry ') gives the solubility of these salts as under :

| | Cold Water | Boiling Water |
|---|---|---|
| | Mlgr. per 100 c.c. | Mlgr per. 100 c.c. |
| Magnesium carbonate . | 1 in 2493 = 40 | 1 in 9000 = 11·1 |
| Calcium carbonate . | 1 in 8834 = 11·6 | 1 in 10,601 = 9·5 |

whereas in Thorpe's 'Dictionary of Applied Chemistry,' 100 c.c. of water is said only to dissolve 1·8 mlgr. of calcium carbonate. This result is probably too high.

Whipple and Meyer[1] in the United States have recently gone thoroughly into the question of the solubility of calcium carbonate and magnesium hydrate in waters, and have shown that all previous results are fallacious and too high.

Using Jena glass vessels, and correcting for the action of the water on the glass and working in such a manner that access of $CO_2$ was practically impossible, they found that:

1. The solubility of $CaCO_3$ at ordinary temperatures is 1·3 parts per 100,000.
2. The solubility of Mg2HO is from 1·0 to 1·2 parts per 100,000.

The saline constituents having been determined, or at least the free carbonic acid and the $CO_3$ present in combination, and the calcium and magnesium, it can at once be told whether lime alone will soften the water to the required extent or whether sodium carbonate will also have to be used. Some water authorities are required to soften down to 8° or 10°, one authority has only to soften to 18°, whilst still others are required to 'effectually' soften the water by Clark's or similar process. This really means that the water shall be softened to within 1° to 2° of its permanent hardness by the proper application of lime. If the word 'similar' is omitted, then any other softening process, such as the Permutit system, could be employed.

When the permanent hardness is not excessive, lime alone need be used. This applies to nearly all chalk-derived waters, which are easily softened. When a water contains much calcium sulphate also, sodium carbonate as well as lime must be employed, and there is little difficulty in calculating the amount of chemicals required and in producing satisfactory results. When a water contains much magnesium salts, trouble begins, and if the water is variable in character, efficient softening is only possible when the works are under skilled supervision.

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[1] *Journal of Infectious Diseases*, Suppl. No. 2., February 1906.

The amount of lime, CaO, and sodium carbonate theoretically required for any water may be calculated by aid of the following Tables:

1 mlgr. free $CO_2$ requires 1·27 CaO to convert it into $CaCO_3$.

$$CaO + CO_2 = CaCO_3.$$

1 mlgr. $CaCO_3$ (existing in the water as $CaC_2O_5$) requires 0·56 mlgr. CaO to convert it into $CaCO_3$.

$$CaC_2O_5 + CaO = 2CaCO_3.$$

1 mlgr. $MgCO_3$ (which possibly exists in the water as $MgC_2O_5$) requires 1·3 mlgr. CaO to convert it into MgO.

$$MgC_2O_5 + 2CaO = MgO + 2CaCO_3.$$

1 mlgr. Mg (existing as sulphate, chloride or nitrate) requires 2·3 mlgr. CaO to convert it into MgO.

$$MgSO_4 + CaO = MgO + CaSO_4.$$

1 mlgr. Ca (as sulphate, chloride or nitrate) requires 2·65 mlgr. $Na_2CO_3$ to convert it into $CaCO_3$.

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

1 mlgr. Mg (as sulphate, &c.), the lime added having produced an equivalent of $CaSO_4$, will require 4·4 mlgr. $Na_2CO_3$ to convert this into $CaCO_3$.

$$MgSO_4 + CaO + Na_2CO_3 = MgO + CaCO_3 + Na_2SO_4.$$

The following examples will show how this Table is used. A Hertfordshire chalk-water was found to contain in each 100 c.c.

| | |
|---|---|
| Free $CO_2$ | 2·8 mlgr. |
| $CaCO_3$ | 24·5 ,, |
| $MgCO_3$ | 4·2 ,, |

and only a small quantity of other magnesium or calcium salts.

Upon boiling, the hardness, which was 30°, was only reduced to 10°.

2·8 $CO_2$ × 1·27 = 3·6 mlgr. CaO
24·5 $CaCO_2$ × 0·56 = 13·7 ,, ,,
4·2 $MgCO_3$ × 1·3 = 5·6 ,, ,,
Total 22·9 ,, ,, per 100 c.c. of water.

A water from the coal measures which it was desired to soften gave the following results upon analysis :

Ca 11·75, Mg 4·0, Free $CO_2$ 2·2, $CO_3$ 21·4 per 100,000.

This would correspond to—

2·2 mlgr. free $CO_2$
29·4 ,, $CaCO_3$
5·5 ,, $MgCO_3$
2·5 ,, residual Mg which existed as sulphates.

Lime required to decompose the carbonates, &c.—

2·2 × 1·27 = 2·8 mlgr. per 100 c.c.
29·4 × 0·56 = 16·5 ,, ,,
5·5 × 1·3 = 7·1 ,, ,,
Total 26·4 ,, ,,

Sodium carbonate and lime required in addition for the residual Mg—

2·5 × 2·3 = 5·75 mlgr. CaO
2·5 × 4·42 = 11·05 mlgr. $Na_2CO_3$

or a total of 32·15 parts of lime and 11·05 parts of sodium carbonate for 100,000 parts of the water. As a gallon of water weighs 10 lb., each 1000 gallons would require 3¼ lb. of lime and 1·1 lb. of sodium carbonate. The amount of lime and sodium carbonate of commerce which would be required would depend upon the quality of the chemicals used.

In all lime processes of softening, the lime is added to a portion of the water to be treated, either to make milk of lime or lime-water. The best results are produced if lime-water is made, and, assuming that good lime is used, each gallon of lime-water made should contain about 70 grains of lime (= 1 mlgr. per c.c.) Such being the case the above water would require, for removal of the carbonates only, that 26¼ gallons should be converted into lime-water and be added to a further 100 gallons. If all the magnesium is to be removed, then 32 gallons must be converted into lime-water and 1026 grains of sodium carbonate added, and this be mixed with a further 100 gallons of water.

Before giving the results of actual experiments, showing that these theoretical considerations can merely give a rough indication of the lime, &c., needed in actual work, it is necessary to describe how the effect of different quantities of the reagents on a water can be determined.

At softening works the silver nitrate test is usually employed for ascertaining whether enough lime is being used. When a solution of this silver salt is added to a water free from lime (CaO) a white turbidity, due to the sodium chloride in solution, is produced. If there is lime present the turbidity is no longer white, but grey-brown to nearly black, according to the amount of lime present, the colour being due to the production of silver oxide. The test is not sufficiently delicate, but with care it suffices for practical purposes if applied in the following manner: Lime-water is added to the crude water until silver nitrate gives a distinct reaction, more crude water is then run in until the mixture is no longer discoloured by the test. Where the water is constant in character, usually nothing is done beyond testing the softened water from time to time to see that it contains no excess of lime.

An attempt has been made to utilise phenolphthalein as a test, but inasmuch as the reagent is affected by carbonates in solution as well as by hydrates, it is worse than useless in the hands of a working man. In the laboratory the result of adding different quantities of lime and sodium carbonate can be followed with ease if once the principles underlying the process are grasped.

A portion of the water to be used is made into lime-water and the amount of lime therein estimated by means of $\frac{n}{10}$ hydrochloric or sulphuric acid, using PT as an indicator. If sodium carbonate is also to be used a solution is made containing 1 mlgr. $Na_2CO_3$ per c.c. Various proportions of these can be added to ½ or 1 litre of water, and after gentle agitation portions of the liquid can be filtered off and used for ascertaining the hardness; and for the following tests: With magnesia waters the hardness, as ascertained by the soap test, rarely agrees with that calculated from the results of the other tests.

To 100 c.c. of the filtered water, in a Nessler glass, add a few drops of PT solution and a single drop of delicate methyl orange solution. Stand on a white plate and add from a burette, droplet by droplet, $\frac{n}{10}$ acid until the red PT colour has disappeared. Note the amount used and continue the addition of the acid until the red tint due to the action of free acid upon MgO appears. With a little experience using the above quantities, excellent results are obtainable. The amount of acid used in the first instance may be called *a* and the total amount used *b*. *a* represents the amount of acid required to neutralise any excess of lime present, plus the amount required to convert the carbonates, remaining in solution into bicarbonates (i.e. half the amount actually required to decompose the carbonate), whilst *b* will represent the amount required to neutralise the lime and decompose the carbonates and bicarbonates.

Let $x =$ the number of c.c. of acid required to neutralise the free lime;

$y =$ the number of c.c. of acid required to decompose the carbonates;

$z =$ the number of c.c. of acid required to decompose the bicarbonates.

We may safely assume that free lime and bicarbonates cannot exist in the same solution, therefore in any solution either $x$ or $z = 0$.

$$a = x + \tfrac{1}{2}y$$

$$b = x + y + z$$

therefore $$2a - b = x - z$$

If $2a$ exceeds $b$, then $x - z$ is a positive quantity, and as one or the other must $= 0$, $x$ must be positive, and $z = 0$, in other words lime, CaO, must be present.

If, on the other hand, $2a$ is less than $b$, $z$ must be a positive quantity, in which case bicarbonates are present and lime absent, consequently $x = 0$.

When $z = 0$, then

$$a = x + \tfrac{1}{2}y$$
$$b = x + y$$

therefore $x = 2a - b$ and $y = b - x = 2(b - a)$

When $x = 0$, then

$$a = \tfrac{1}{2}y$$
$$b = y + z$$

therefore $y = 2a$ and $z = b - y = b - 2a$

$y$ is always positive, but during the softening process, &c., its value changes rapidly. Under certain circumstances a considerable amount of carbonate may remain in solution for a quarter of an hour, after which it is more or less quickly deposited, and upon the rate of this deposition depends the rapidity of the softening process.

In the following experiment, the chalk-water referred to on page 412 was used. The lime-water made from it contained 1·1 mlgr. $CO_2$ in each c.c.

For ascertaining by actual experiment the best proportion of lime-water to use, half a litre of water was placed in each of four litre cylinders, and 20, 22, 24 and 26 c.c. of lime-water added per 100 c.c. of the water contained in the respective cylinders. The water was gently agitated as the lime-water was being added. After standing various periods, portions were filtered off and examined, with the results shown on page 417.

With 20 per cent. of lime-water of the strength used, the hardness was reduced to 8°,[1] leaving a little calcium bicarbonate in solution. The reaction was practically complete in a quarter of an hour.

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[1] The hardness theoretically should be $b \times 5$, as each c.c. of the acid used in estimating $b$ corresponds to 5 mlgr. $CaCO_3$.

After half an hour there is not likely to be any further deposition.

With 22 per cent. of lime-water, a trace of free lime made its appearance, but the amount was too small to affect the character of the water.

With 24 per cent. more lime but less carbonates remained in the softened water, the result being a reduction of the hardness to 6½°. As at the end of two hours the free lime amounted to 0·7 × 2·8 = 1·96 parts per 100,000, or 1·4 grains per gallon, this would absorb carbon dioxide and deposit chalk in the mains. With 26 per cent. of lime-water the hardness was reduced to 8° in one hour and fell to 6° in three hours, doubtless from absorption of $CO_2$ from the air. This water would not be safe to turn into the mains. The conclusion to be drawn from the series of experiments is that this particular water mixed with 20 to 22 per cent. of lime-water of the strength used or its equivalent of a weaker solution would reduce the hardness of the water to 8° without any danger of further deposition of insoluble carbonates in the mains.

| Proportion of Lime Water | Time | *a* | *b* | *x* | *y* | *z* | Hardness. |
|---|---|---|---|---|---|---|---|
| 20 c.c. to 100 of water . | ¼ hour | ·6 | 1·7 | ·0 | 1·2 | ·5 | — |
| ,, ,, ,, . | 1 ,, | ·6 | 1·65 | ·0 | 1·2 | ·45 | 8° |
| 22 cc. to 100 of water . | ¼ ,, | 1·3 | 2·3 | ·3 | 2·0 | 0 | — |
| ,, ,, ,, . | 1 ,, | ·9 | 1·6 | ·2 | 1·4 | 0 | 8° to 9° |
| ,, ,, ,, . | 2 ,, | ·85 | 1·5 | ·2 | 1·3 | 0 | 8° |
| 24 c.c. to 100 of water . | ¼ ,, | 1·55 | 2·1 | 1·0 | 1·1 | 0 | — |
| ,, ,, ,, . | 1 ,, | 1·1 | 1·5 | ·7 | ·8 | 0 | — |
| ,, ,, ,, . | 2 ,, | 1·1 | 1·5 | ·7 | ·8 | 0 | 6½° |
| ,, ,, ,, . | 3 days | ·5 | 1·0 | ·0 | 1·0 | 0 | 6° |
| 26 c.c. to 100 of water . | ¼ hour | 3·1 | 5·0 | 1·2 | 3·8 | 0 | — |
| ,, ,, ,, . | 1 ,, | 1·55 | 1·9 | 1·2 | ·7 | 0 | 8° |
| ,, ,, ,, . | 2 ,, | 1·25 | 1·55 | ·95 | ·6 | 0 | — |
| ,, ,, ,, . | 3 ,, | 1·0 | 1·25 | ·75 | ·5 | 0 | 6° |

By using a slightly larger proportion of lime-water the hardness could be reduced to 6°, but with the inevitable result that deposits would form in the mains, unless the water was stored for some days before leaving the works or was recarbonated.

Another example may be given of a water which it is extremely difficult to treat, inasmuch as it varies much in character. It is derived from a disused mine which contains some 400 feet of water. Samples taken at different depths vary considerably. Samples taken at various levels down to 300 feet, at which depth all ordinary bottles were crushed in with explosive violence, show a gradual increase in hardness. When the water is being pumped the hardness increases as the water level falls. Moreover there is often a distinct change in character. The water referred to on p. 413 was from this well, and it contained carbonates of calcium and magnesium and magnesium sulphate, whereas the next sample sent contained calcium carbonate and sulphate and magnesium sulphate, but no magnesium carbonate. The amount of lime required for softening had been calculated from results obtained with the first sample, but it was soon found that chalk was depositing in the mains and that the water was not being properly softened to 18° (Clarke). The tests applied at the works proved useless. PT gave a marked reaction when the lime added was far from being sufficient, and silver nitrate did not give a definite reaction unless a marked excess of lime was being used.

A carboy of what was considered an average sample was taken and used in the following experiments. Upon analysis the water was found to contain :

| | | |
|---|---|---|
| Calcium carbonate . . | 29·2 | parts per 100,000 |
| Calcium sulphate . . | 1·0 | ,, ,, ,, |
| Magnesium sulphate . | 15·3 | ,, ,, ,, |
| Sodium sulphate . . | 5·3 | ,, ,, ,, |
| Sodium chloride . . | 4·5 | ,, ,, ,, |
| Free carbonic acid . . | 1·1 | ,, ,, ,, |
| Total solids . . | 56·1 | ,, ,, ,, |

From the analysis it would appear to be an easy matter to soften this to 26° (18° Clarke's), yet this can only be practically effected (without the use of sodium carbonate) by using a large excess of lime-water.

The lime-water used in the experiments was made with the water to be softened, and contained 1·1 mlgr. CaO per c.c.

The CaO required to remove the $CO_2$ is 1·1 × 1·27 = 1·4 mlgr.

The CaO required to remove the $CaCO_3$ is 29·2 × 0·56 = 16·3 mlgr.

Total: 17·7 mlgr. = to 16 c.c. of the lime-water.

To decompose the magnesium sulphate would require 3·1[*] × 2·3 = 7·1 mlgr. CaO or 6·5 c.c. of the lime-water. Therefore, to precipitate the calcium carbonate and decompose the magnesium sulphate 22·5 c.c. of lime-water would be required for each additional 100 c.c. of the water.

This quantity was added to the water, and after standing all night a complete analysis was made with the following results:

Ca 5·5, Mg 0·5, $CO_3$ 1·5, $SO_4$ 16·5, Cl 2·7, $NO_3$ 0·06 per 100,000.

| | |
|---|---|
| **Calcium carbonate** | **2·5** |
| **Calcium sulphate** | **15·3** |
| **Magnesium sulphate** | **2·4** |
| **Sodium sulphate** | **5·6** |
| **Sodium chloride** | **4·5** |
| **Total solids** | **33·5** |

A sample which had stood four hours only contained free alkali, and gave, upon analyses, the following results:

| | |
|---|---|
| **MgO** | **0·75 mlgr per 100 c.c.** |
| **CaO** | **0·5 mlgr per 100 c.c.** |
| **$CaCO_3$** | **1·75 mlgr. per 100 c.c.** |

The following experiments were made with this water: 200 c.c were placed in each of six cylinders, and 14, 16, 18, 20, 22 and 24 c.c. of lime-water per 100 c.c. added to the respective jars. At the expiration of an hour all were filtered and examined with the following results:

| Lime-water per 130 c.c. | *a* | *b* | *x* | *y* | *z* | Hardness (Clarke) |
|---|---|---|---|---|---|---|
| 14 c.c. | ·4 | 1·6 | ·0 | ·8 | ·8 | 22½° |
| 16 ,, | ·65 | 1·4 | ·0 | 1·3 | ·1 | 22½° |
| 18 ,, | ·9 | 2·0 | ·0 | 1·8 | 2· | 23° |
| 20 ,, | 1·0 | 1·7 | ·3 | 1·4 | 0 | 22½° |
| 22 ,, | ·85 | 1·2 | ·5 | ·7 | 0 | 21° |
| 24 ,, | ·9 | 1·2 | ·6 | ·6 | 0 | 17° to 18° |

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[*] 3·1 = the residual magnesium = the magnesium in 15·3 parts of $MgSO_4$.

Apparently the best results were obtained by using even more lime-water than was required for both carbonates and sulphates, therefore an endeavour was made to check these results by experiments in which larger quantities of water were used (500 c.c.) and examination of the filtrates at various intervals. The results did not coincide, and emphasised the difficulty of predicting what exactly would occur.

| Lime-water to 100 c.c. | Time | $a$ | $b$ | $x$ | $y$ | $s$ | Hardness (Clarke) |
|---|---|---|---|---|---|---|---|
| 16 c.c. . . . . . | ¼ hour | 2·4 | 4·3 | ·5 | 3·8 | 0 | — |
| | 1 ,, | 1·6 | 2·7 | ·5 | 2·2 | 0 | — |
| | 2 ,, | ·9 | 1·5 | ·3 | 1·2 | 0 | 21° |
| | 4 ,, | ·65 | 1·1 | ·2 | ·9 | 0 | 19° |
| 20 c.c. . . . . . | ¼ ,, | 3·3 | 5·6 | 1·0 | 4·6 | 0 | — |
| | 1 ,, | 1·3 | 2·85 | ·45 | 1·7 | 0 | 21° |
| | 2 ,, | 1·10 | 1·9 | ·3 | 1·6 | 0 | 20° |
| | 4 ,, | ·7 | 1·15 | ·25 | ·9 | 0 | 17° |
| 20 c.c. . . . . . | ¼ ,, | 2·3 | 4·2 | ·4 | 3·8 | 0 | — |
| (water poured into the lime-water) | 1 ,, | 1·1 | 1·7 | ·4 | 1·3 | 0 | 19° |
| | 2 ,, | ·9 | 1·35 | ·45 | ·9 | 0 | 17° |
| | 4 ,, | ·5 | .35 | ·15 | ·7 | 0 | 15° |
| 22 c.c. . . . . . | ¼ ,, | 3·5 | 5·9 | 1.1 | 4·8 | 0 | — |
| | 1 ,, | 2·3 | 3·7 | ·9 | 2·8 | 0 | 24½° |
| | 2 ,, | 1·5 | 2·4 | ·6 | 1·8 | 0 | 20° |
| | 4 ,, | ·85 | 1·45 | ·25 | 1·2 | 0 | 19° |
| 24 c.c. . . . . . | ¼ ,, | 2·5 | 4·8 | ·2 | 4·6 | 0 | — |
| | 1 ,, | 1·3 | 2·3 | ·3 | 2·0 | 0 | — |
| | 2 ,, | 1·0 | 1·75 | ·25 | 1·5 | 0 | — |
| | 4 ,, | ·8 | 1·4 | ·2 | 1·2 | 0 | 19° |

Previous results had led me to suspect lack of uniformity, hence the experiment with 20 c.c. was duplicated. In the first the lime-water was added to the water in the usual way, in the second the water was poured into the lime-water. Both results, however, were better than those obtained with either smaller or larger quantities of lime, but these and other experiments tend to prove that this water cannot be uniformly softened to 18° (Clarke) by the use of lime alone. The reaction takes too long a time for completion, and there would certainly be grave risk of deposition occurring in the mains. Theoretically, by the use of lime and sodium carbonate, the water should permit of being softened down to 3° or 4°. This would require the use of 13·5 mlgr. $Na_2CO_3$ per 100 c.c. in addition to the lime.

The following experiments were then made, each mixture being allowed to stand three hours before examination :

| CaO added | $Na_2CO_3$ | *a* | *b* | *x* | *y* | *z* | Hardness |
|---|---|---|---|---|---|---|---|
| 23·5 . . . . . . | 13·5 | ·9 | 1·6 | ·2 | 1·4 | 0 | 12° |
| 26·7 . . . . . . | 13·5 | 1·15 | 1·8 | ·5 | 1·3 | 0 | 10° |
| 30·0 . . . . . . | 13·5 | 1·5 | 1·9 | 1·1 | ·8 | 0 | 10° |
| 32·0 . . . . . . | 13·5 | 1·8 | 2·35 | 1·25 | 1·1 | 0 | 11° |
| 21·4 . . . . . . | 13·2 | 1·2 | 2·0 | ·4 | 1·6 | 0 | 13° |
| 21·4 . . . . . . | 10·6 | 1·2 | 1·7 | ·7 | 1·0 | 0 | 12·5° |

A larger quantity was put on, to which 24·4 mlgr. CaO and 14·3 mlgr. $Na_2CO_3$ was added, and this was examined at intervals with the following results :

| Time | *a* | *b* | *x* | *y* | *z* | Hardness |
|---|---|---|---|---|---|---|
| ¼ hour . . . . . . | 2·1 | 5·3 | — | 4·2 | 1·1 | 18° |
| 1 ,, . . . . . . | 1·85 | 3·1 | ·6 | 2·5 | 0 | 14° |
| 3 hours . . . . . . | 1·6 | 2·6 | ·6 | 2·0 | 0 | 14° |
| 5 ,, . . . . . . | 1·4 | 2·25 | ·55 | 1·7 | 0 | 12° |
| 20 hours . . . . . . | 1·1 | 1·9 | ·3 | 1·6 | 0 | 10° |
| 28 ,, . . . . . . | 1·1 | 1·9 | ·3 | 1·6 | 0 | 9·5° |
| 36 ,, . . . . . . | ·9 | 1·6 | ·2 | 1·4 | 0 | 7½° |

This last sample, at the end of three hours, gave the following results upon analysis :

| Ca | Mg | O | $CO_2$ | $SO_4$ | — | |
|---|---|---|---|---|---|---|
| 1·05 | 1·6 | ·1 | 4·2 | 1·2 | $CaCO_3$ . | 2·65 |
| 1·05 | — | — | 1·6 | — | Mg $CO_3$ . | 3·65 |
| — | 1·05 | — | 2·6 | — | Mg O . | ·40 |
| — | ·24 | ·16 | — | — | Mg. $SO_4$ . | 1·50 |
| — | ·3 | — | — | 1·2 | — | |

The above would correspond to a hardness of 9¼° per 100,000 or 6½° (Clarke), whereas 7½° was obtained by the soap-test.

All these experiments show that time is an important factor in the softening process, and that magnesia Mg2HO more rapidly precipitates than $CaCO_3$. Whipple and Meyer (*loc. cit.*) found that when lime-water was added to a solution of calcium bicarbonate several days are required for completion of the reaction, and that it was more rapid at 37° C. than at lower temperatures. After six hours, however, the amount of $CaCO_3$ formed or deposited is very small. These observers also state that the after-deposits occurring in softened water rarely contain any magnesia. They think that the slower deposition of the lime salt is due to the fact that the $CaCO_3$ is crystalline, whereas the magnesium hydrate deposits in a colloidal condition.

When the amount of chemical required has been ascertained by experiment the cost can easily be calculated. The water from this particular source has been treated, but with occasional unsuccessful results, with 2·1 lb. lime and ½ lb. of sodium carbonate per 1000 gallons.

Lime delivered at the works costs 30*s*. per ton, and 90 per cent. soda costs 120*s*. per ton.

| | |
|---|---|
| 2·1 lb. lime . . . . . . | 0·34*d*. |
| ·5 lb. soda . . . . . . . | 0·4*d*. |

or ¾ of a penny per 1000 gallons for chemicals alone.

A sample so softened gave the following results in parts per 100,000 :

Before softening, Ca 12·0, Mg 3·1, $CO_3$ 17·5, $SO_4$ 16·5, Cl 2·7.

After softening, Ca 5·5, Mg ·5, $CO_3$ 1·5, $SO_4$ 16·5, Cl 2·7, giving as probable constituents :

| | Before Softening | After Softening |
|---|---|---|
| Calcium carbonate . . . . . | 29·2 | 2·5 |
| Calcium sulphate . . . . . | 1·0 | 15·3 |
| Magnesium sulphate . . . . . | 15·3 | 2·4 |
| Sodium sulphate . . . . . | 5·3 | 5·6 |
| Sodium chloride . . . . . . | 4·5 | 4·5 |
| Hardness (Clarke) . . . . | 33° | 18·5° (theory 14°) |

The ' Permutit ' system of softening removes all the magnesium and calcium salts, sodium replacing these bases, reducing the hardness practically to 0°. By softening an aliquot part and mixing with untreated water, a mixture of any degree of hardness can be obtained. Thus, by completely softening half the above water and mixing with the unsoftened remainder, the hardness would be 16·5° As stated in a previous section I do not think this treatment affects the wholesomeness of the water.

## DETERMINATION OF IODINE AND BROMINE, IODIDES AND IODATES, BROMIDES AND BROMATES

When examining waters suspected to be contaminated with sea-water it is often desirable to ascertain whether bromides can be detected, as these are always present in sea-water in very easily detectable quantity. When examining a series of Essex deep well-waters which, I believe, contain sea-water altered by filtration through zeolitic sands, I had very little difficulty in discovering bromides in the saline residue, and I obtained indications of the presence of other compounds, both of bromine and iodine. Attempts to estimate the quantities present were more or less failures, as no process described gave concordant results. The working out of a process has necessitated nearly a year's work, and it is doubtful even now whether all the factors essential to secure accuracy have been discovered. The process to be described was worked out in stages, using at first simple aqueous solutions of iodides, iodates, bromides, and bromates. Then various salts were added, such as sodium chloride, &c., to ascertain the effect of their presence, then mixtures of iodides, iodates, &c., were tried without and with admixture of such salts as occur in potable waters.

The first process fully worked out was found to require modification when tried with the natural brominated water of Woodhall Spa ; but using waters of this character, results are now obtainable which appear to be perfectly reliable if all the details are carefully carried out, and experience has been gained by examining a few artificially prepared waters containing known quantities of iodine and bromine compounds. The reagents required are:

1. Freshly prepared chlorine water made from washed chlorine gas, and free from any trace of acid, and of such strength that 1 c.c. will liberate about 0·5 mlgr. of iodine.

2. Solution of sodium thiosulphate of such strength that 1 c.c. corresponds to about 0·5 mlgr. iodine.

3. Purified petrol. Commercial petrol is treated with bromine until a red colour remains distinct at the end of twenty-four hours. It is then washed with dilute caustic soda solution until perfectly colourless, and then with successive quantities of distilled water until the washings are neutral and give no opalescence with silver nitrate.

Apparatus—50 and 100 c.c. stoppered cylinders, &c.

*Process.*—To the water to be evaporated a drop of phenolphthalein solution is added and sufficient pure carbonate of soda to give an alkaline reaction. Evaporate in a Jena glass flask, adding sodium carbonate from time to time to maintain a distinct pink colour. When reduced to about 100 c.c. filter off the insoluble residue, wash this with distilled water, and again evaporate until crystals begin to form. Cool and dissolve any crystals deposited in a little water. Add a droplet of very sensitive methyl orange and neutralise with the utmost care with $\frac{n}{10}$ hydrochloric acid. The liquid may have a perceptible red tint, but if 0·1 c.c. of the acid be added in excess, and iodates and iodides are present, these will react and lead to a slight error. On the other hand, if any carbonate remains in the liquid, both the iodide and bromide determinations will be affected.

Whilst the evaporation is taking place, the reagents may be standardised. The thiosulphate against a $\frac{n}{10}$ iodine solution, and the chlorine water against solutions of bromide and of iodide in distilled water, using known quantities of iodide and bromide, and titrating in the manner described below.

Divide the evaporated solution into three equal parts. Use one for the determination of the iodides and bromides, and a second for the iodates and bromates, and the third for repeating either.

*Estimation of the Iodide.*—To one portion of the concentrated water in a narrow stoppered cylinder add about 3 or 4 c.c. of purified petrol, and drop in the chlorine water, drop by drop at first, with constant agitation. (More than 0·5 c.c. must never be added at a time.) After each addition, remove the coloured petrol, transferring it to another cylinder. Continue this until, with the last drop of chlorine water added, the red colour due to the methyl orange suddenly disappears. This indicates the point at which all the iodide has been decomposed. Wash the removed petrol with 1 or 2 c.c. of distilled water and transfer the washings to the aqueous solution. Continue the addition of chlorine water to the iodine solution in the petrol until all the colour is discharged. Vigorous agitation and time is required towards the end of the reaction.

From the amount of chlorine water used, the quantity of iodine present as iodide is simply calculated.

*Estimation of the Bromide.*—About 5 c.c. of petrol is now added to the aqueous solution and the addition of chlorine water continued. 1 or 2 c.c. may be necessary to produce any distinct coloration of the petrol. Proceed *secundum artem* until the bromine liberated is completely decolourised, time and vigorous agitation being necessary towards the end of the reaction. The amount of chlorine water used indicates the amount of bromine present as bromides.

If the chlorine water used was standardised against solutions of iodide and bromide differing greatly in strength from that of the solution examined, it is desirable to restandardise, using solutions approximately of the strength of the concentrated water.

*Estimation of Iodates.*—To another portion of the concentrated water, add 1 per cent. of 33 per cent. acetic acid (free from any trace of mineral acid) and a little pure potassium iodide. Allow it to stand for at least five minutes, and, if any iodine is liberated, titrate with the sodium thiosulphate, using a single drop of starch solution as an indicator. One-sixth of the iodine estimated will correspond to the iodine present as iodate.

*Estimation of Bromates.*—To the solution in which the iodate has been estimated, add 1 per cent. of pure strong hydrochloric acid and set aside for half an hour. Estimate the iodine liberated with thiosulphate, and one-sixth of this multiplied by $\frac{80}{127}$ will give the amount of bromine present as bromates.

The following results will show the accuracy of the process. Some determinations were made by an assistant from solutions made by me; others were made by me from solutions prepared by my assistants:

| Nature of Solution used. | Salts present in mlgr. per 100 c.c. | | | | | |
|---|---|---|---|---|---|---|
| | I as KI | I in $KIO_3$ | Total I | Br in NaBr | Br in $NaBrO_3$ | Total Br |
| 1 Sol. in distilled water taken . | 1·0 | 1·0 | 2·0 | 10·0 | 1·0 | 11·0 |
| Found . . . . . . | ·98 | 1·03 | 2·01 | 10·3 | 1·01 | 11·31 |
| 2 Sat. sol. of $NaHCO_3$ taken . | 1·0 | 0·0 | 1·0 | 10·0 | 1·0 | 11·0 |
| Found . . . . . . | 1·2 | 0·0 | 1·2 | 10·4 | 1·01 | 11·41 |
| Taken in 3 to 6 . . . | ·5 | ·5 | 1·0 | 5·0 | ·5 | 5·5 |
| 3 Found in 20 % brine . . | ·49 | ·55 | 1·04 | 4·93 | ·51 | 5·44 |
| 4 „ 20 % $Na_2SO_4$ . . | ·52 | ·50 | 1·02 | 5·2 | ·49 | 5·69 |
| 5 „ 10 % NaCl and 10 % $Na_2SO_4$ . . | ·49 | ·49 | ·98 | 5·0 | ·47 | 5·47 |
| 6 „ 10 NaCl and 10 % $Na_2CO_3$ . . | ·46 | ·48 | ·94 | 5·05 | ·53 | 5·58 |
| Imitation of a litre of natural brominated water containing calcium and magnesium salts and NaCl. | | | | | | |
| 7. Taken . . . . . . | 2·0 | 2·0 | 4·0 | 70·0 | 4·0 | 74·0 |
| 8. Found . . . . . . | 1·8 | 1·95 | 3·75 | 68·0 | 3·92 | 71·92 |
| 9. The above varied. Taken . | 1·0 | 2·0 | 3·0 | 30·0 | 2·0 | 32·0 |
| 10. Found . . . . . . | ·85 | 2·02 | 2·87 | 30·4 | 2·02 | 32·42 |

A trace of nitrite, if present, vitiates all the results.

In the presence of nitrites the bromine cannot be accurately estimated. Upon adding chlorine water to such a solution many c.c.'s have to be added before the petrol has any perceptible colour, and the maximum colour produced, even with a strong bromide solution, is only a pale orange. The end reaction is also most indefinite. I have not yet succeeded in estimating the bromides in the presence of nitrites. Their presence also renders it impossible to determine the iodates and bromates.

By digesting the concentrated water for an hour at room temperature with zinc copper couple (made from zinc dust), the nitrites, iodates, and bromates are all reduced, and the total iodine and bromine can be estimated when certain precautions are observed. If the nitrites are destroyed by means of urea, the iodates and bromates may possibly be determined.

The following results were obtained with a litre of water containing about 0·1 gram of sodium nitrite, &c.:

| | Added to the Water. | Found. |
|---|---|---|
| Iodine as Iodide . . . . | 2·0 | 1·75 |
| „ as Iodate . . . . | 2·0 | 2·2 |
| Total Iodine . | 4·0 | 3·95 |
| Bromine as Bromide . . . | 18·6 | 18·5 |
| „ as Bromate . . . | 2·0 | 1·35 |
| Total Bromine . | 20·6 | 19·85 |

# CHAPTER XVII

## EXAMINATION OF WATER BY ELECTRICAL METHODS

It is a well-known fact that the electrical conductivity of any sample of water depends almost entirely, if not entirely, upon the substances dissolved in it, and providing the solution is very dilute the conductivity is proportional to the percentage of the substance dissolved in the water. Unfortunately the determination of the conductivity tells us nothing as to the nature of the substance in solution, but if this increases or decreases in amount so does the conductivity increase and decrease, and if the conductivity of a water is ascertained, then any change in the character of the water will be indicated by a change in the conductivity.

Based on these facts, Messrs. Digby and Biggs have devised an apparatus which is exceedingly simple in character, and which is likely to be useful for many purposes. Their description of it is as follows:

The complete apparatus is shown in Fig. 11, where G is a bent glass tube to contain the water under test, and A and B are the electrodes for passing the electric current through the water. The electrodes are connected by wires to a direct-reading conductivity meter M, and a continuous-current hand-driven dynamo E; so that by turning the handle W of the dynamo, a current traverses the meter and the water in the conductivity tube G. The pointer of the meter is deflected, and comes to rest at some point upon the scale which directly indicates the conductivity of the water in the tube. The test is completed as soon as the pointer has come to rest, that is to say, in two or three seconds.

Referring again to Fig. 11, it will be seen that the conductivity tube is so constructed that by pouring water into the funnel F, and allowing it to overflow through the outlet pipes O O, every part of the tube is thoroughly washed out, and any products of electrolysis which may have accumulated upon the electrodes are at the same time swept away by the water. The air vents V V ensure a steady flow from each outlet without any syphoning action. A drain pipe D of pure rubber is provided at the bottom of the tube for the purpose of drawing off the contents at the conclusion of a test. Normally, the drain is closed by a pinch-cock. Water may be left standing in the tube for days at a time without the slightest trace of contamination from the rubber finding its way into the conductivity tube. The only other materials in contact with the contents of the tube are glass and platinum.

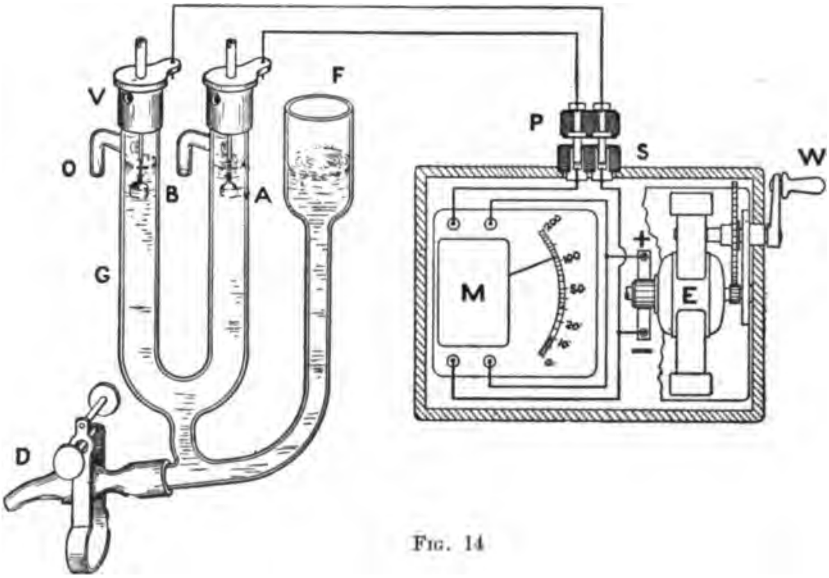

FIG. 14

The tube is mounted on a strong teak stand designed to afford as much protection as is consistent with accessibility.

The conductivity meter and dynamo are fixed inside a box and once for all connected up to each other and to the terminals of the socket S, which is fixed on the outside of the box. The two-pin plug P is permanently connected up to the electrodes A and B by means of a short length of well-insulated twin-flexible cable. Hence, all the user has to do in order to connect the tube to the meter is to push the plug into the socket.

When a reading is taken the temperature is recorded and a correction made to obtain the conductivity at 20° C.

$$K = M \times \frac{100}{56 + 2{\cdot}2\,T}$$

where K = conductivity required, M = observed conductivity, and T = temperature at time of experiment.

When the conductivity of samples to be examined is very high the apparatus is modified so as to permit of greater accuracy in the readings.

The unit adopted is the reciprocal of one megohm, and in the apparatus as ordinarily supplied the scale extends from zero to 2000 units.

The patentees give a Table of conductivities of various waters, which is reproduced on p. 431.

The apparatus may be used for ascertaining whether any change has taken place in the character of a water, and thus indicate the necessity for an analysis to be made. It may be employed for detecting the leakage in steam condensers, for detecting priming in steam boilers, and for controlling water-softening plants. With London tap-water of 14·5 hardness, Mr. Digby found that by adding successive quantities of lime the conductivity decreased to a minimum at the point, when only permanent hardness remained, and increased again when more lime was added, that is when the lime was in excess. He says: 'The conductance tube may serve . . . to ascertain the point at which the addition of lime should be discontinued in the Clark process of softening, as any excess of lime is made apparent by the rise in conductance.'

## *Table of the Conductivities of Various Waters*

With the exception of the value recorded by Kohlrausch, all the following figures have been obtained by means of the Dionic Water-tester.

| No. | Source of Water | Conductivity at 20° C. |
|---|---|---|
| | DISTILLED WATER: | |
| 1 | Obtained by F. Kohlrausch, after occupying ten years in cleaning the glass-receiver of the distilling apparatus . | 0·2 |
| 2 | Supplied by Messrs. Hopkin & Williams, London; an abnormally pure sample . . . . . . . . | 1·2 |
| 3 | Supplied by Messrs. Hopkin & Williams, London; average of several samples . . . . . . . . | 2·0 |
| 4 | Supplied by a retail chemist, Birmingham . . . | 5·0 |
| 5 | Supplied by a retail chemist, London . . . . | 8·0 |
| 6 | ,, ,, ,, (another sample) . | 14·0 |
| | CONDENSED WATER, from the hot-wells of condensing engines: | |
| 7 | Shoreditch Electricity Works, London . . . . | 3·3 [1] |
| 8 | Westminster Electro Supply Corporation, Eccleston Place Station . . . . . . . . . . . | 3·6 [2] |
| 9 | Messrs. Belliss & Morcom's Works, Birmingham . . | 11·7 [3] |
| | PUBLIC WATER SUPPLIES: | |
| 10 | Glasgow, from Loch Katrine . . . . . . . | 34 |
| 11 | Manchester, from Thirlmere . . . . . . . | 48 |
| 12 | Blackburn . . . . . . . . . . . | 65 |
| 13 | Birmingham, from Rhayader, Wales . . . . | 80 |
| 14 | Dewsbury . . . . . . . . . . . | 109 |
| 15 | Glasgow, from Gorbals Waterworks . . . . | 119 |
| 16 | East Surrey Water Company, from wells in chalk (softened by Clark's process) . . . . . . . . | 135 |
| 17 | London, West Middlesex District (after softening by Clark's process) . . . . . . . . . . . | 163 |
| 18 | London, West Middlesex District (after softening by boiling) | 180 |
| 19 | Southampton . . . . . . . . . . | 185 |
| 20 | Paris . . . . . . . . . . . . . | 312 |
| 21 | London, West Middlesex District (as supplied by the Metropolitan Water Board) . . . . . . . | 390 |
| | COOLING WATER: | |
| 22 | Westminster Electric Supply Corporation, Eccleston Place Station . . . . . . . . . . . | 472 |
| 23 | Messrs. Belliss & Morcom's Works, Birmingham (Canal Water) | 1760 |
| 24 | Sea-water: average of samples taken off Harwich and off the Isle of Wight . . . . . . . . . | 50,000 |

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[1] This is the lowest value observed by Mr. Digby.

[2] This is the calculated value for no leakage; the lowest value observed by Mr. Partridge was 4·1.

[3] The condenser was in perfect order, and the high value is probably due to the discontinuous working of the steam plant.

The following are a few determinations made in my laboratory with this instrument:

| No. | Source of Water. | Conductivity at 20° C. |
|---|---|---|
| 1 | Distilled water. First portion rejected . . . . . | 15·6 |
| 2 | „ „ Later portions collected . . . . . | 6·0 |
| 3 | „ „ All portions collected . . . . . | 3.0 |
| 4 | „ „ No. 3 + 0 25 mlgr. Cl per 100 c.c. . . | 34·8 |
| 5 | „ „ „ + 0 5 „ „ „ . . | 54·0 |
| 6 | „ „ „ + 1·0 „ „ „ . . | 82·8 |
| 7 | Well-water . . . . . . . . . . . | 165· |
| 8 | „ „ + 0 5 mlgr. Cl per 100 c.c.. . . . . . | 185· |
| 9 | Chelmsford tap-water . . . . . . . . . | 1200· |
| 10 | „ „ „ + 1 mlgr. Cl per 100 c.c. . . . | 1200· |
| 11 | „ „ „ + 5 % distilled water . . . | 1120· |
| 12 | „ „ „ after laving hands in it . . . | 1210· |
| 13 | Water from Peterborough (much $Na_2CO_3$) . . . . | 1500. |
| 14 | Lime-stone spring water . . . . . . . . | 410· |
| 15 | „ „ „ „ + 1% distilled water . . . | 410· |
| 16 | „ „ „ „ + 5 „ „ . . . . | 400· |
| 17 | A hard chalk water . . . . . . . . . | 570· |
| 18 | „ „ „ + 8 % of lime-water filtered . . | 450· |
| 19 | „ „ „ + 10 % „ „ „ . . . . | 450· |
| 20 | „ „ „ + 12 % „ „ „ . . . . | 420· |
| 21 | „ „ „ + 14 % „ „ „ . . . . | 420· |
| 22 | „ „ „ + 16 % „ „ „ . . . . | 450· |
| 23 | „ „ „ + 10 % „ „ unfiltered . . | 420· |
| 24 | „ „ „ + 15 % „ „ „ . . . . | 465· |
| 25 | Another chalk-water . . . . . . . . . | 580· |
| 26 | „ „ „ + 7½ % lime-water . . . . . | 450· |
| 27 | „ „ „ + 10 % „ „ . . . . . . | 415· |
| 28 | „ „ „ + 12½% „ „ . . . . . . | 410. |
| 29 | „ „ „ + 14 % „ „ . . . . . . | 455· |
| 30 | A soft Bagshot sand-water . . . . . . . | 60· |
| 31 | Ditto after filtering through chalk . . . . . | 75· |
| 32 | A surface-water of good quality . . . . . . | 44· |
| 33 | Ditto after adding 1 % good sewage effluent . . . | 58· |
| 34 | „ „ „ 2 % „ „ „ . . . . . | 68· |
| 35 | „ „ „ 3 % „ „ „ . . . . . | 75· |
| 36 | „ „ „ 5 % „ „ „ . . . . . | 73· |
| 37 | A very hard limestone-water . . . . . . . | 480· |
| 38 | Ditto after adding 5 % effluent . . . . . . . | 495· |
| 39 | Moderately hard spring water . . . . . . . | 280· |
| 40 | Ditto after adding 5 % effluent . . . . . . . | 300· |

A study of the above Table will show how the apparatus may be utilised. There is no doubt that it is more useful with waters of relatively low conductivity, as the addition to such a water of a little saline matter, or sewage or sewage effluent, makes a considerable difference in the readings, whereas with water of high conductivity the changes observed are not only much less but the readings on the dial are not capable of being read so accurately. The distance traversed by the points from 0° to 5° is equal to that traversed between 100° and 200°, and when the readings are 500° and upwards a reading within 10° is scarcely possible. I understand, however, special dials are constructed for use with waters giving high readings. The one used by me reads from 0° to 2000°, but the scale beyond 500° serves no useful purpose for potable waters.

### THE MEASUREMENT OF RADIOACTIVITY.

Quite frequently now the analyst is asked whether a sample of water contains radium. Without making an analysis he may quite confidently state that it contains that substance or its emanation, but if he is asked to determine the amount he must be prepared to use special apparatus, and an entirely novel method of measurement. Not only so, but he must have had some special experience before he can translate his results into actual figures with any degree of confidence. Joly's work on 'Radioactivity and Geology' should be carefully studied. The few remarks I have to make on the measurement of radium are based upon this work.

At present we have very little evidence to show that the radioactivity of any natural water gives it any special therapeutic property, but its presence seems to many professional men to justify them in making very large claims as to its wonderful effects upon the system. I am not prepared to say that a water richly embued with these emanations may not have some therapeutic use, but merely that, at present, we have no proof of their having any medicinal effect, and that we know nothing of the effects in any single disease. Reference to Joly's work will show that radium and its products of disintegration are found everywhere in sea-water, spring- and river-waters, in the air, and possibly in every mineral. In fact it is ubiquitous. The proportions present in the ocean seem to vary in different localities from $0{\cdot}004 \times 10^{-12}$

grammes per c.c. in the Indian Ocean off Madras to $0\cdot034 \times 10^{-12}$ in the Atlantic round the Irish coast, the mean being $0\cdot017 \times 10^{-12}$ grammes per c.c. Joly estimates that the ocean contains about 20,000 tons of radium, and that to make up for the loss and degradation, if derived from rivers only, these would have to discharge $\frac{1}{2540}$ part (the amount transformed in a year) of that amount into the ocean every year. There is no evidence of any such amount being so carried, hence the radium must be replaced from rocks and other sources. The Nile water only contains 0·0042 and the Rio de la Plata water $0\cdot0052 \times 10^{-12}$ grammes per c.c.

Joly says: 'The widespread presence of radium in the rocks affords an explanation of emanations, not only in spring waters, but in air drawn from soils and in the air of caves.'

There appears to be little doubt that the occurrence of helium in springs, in natural gases, and in the atmosphere (in which, according to Ramsey, it exists to the extent of 4 parts in 10,000) must be ascribed to the general diffusion of unstable elements in the surface crust of the earth. For there is no longer any question of the identity of helium with the alpha rays given off by radium.

Thomson first discovered radium in water. He showed its presence in Cambridge tap-water, and I believe it could be found in every sample of water if carefully examined.

Joly's apparatus consists of (*a*) flask for boiling the water with an inverted condenser attached, (*b*) a bulb-tube for collecting the gases evolved, (*c*) a drying-tube containing phosphoric anhydride, (*d*) an electroscope. Besides these an air-pump is required and a microscope with a scale division, dividing the field into 100 parts in the eye-piece. The figures on page 435 show the apparatus, made for me by Messrs. Gallenkamp and Co., London. The water is boiled in the flask *a* with condenser attached, for thirty minutes. It is then allowed to cool and the flask closed, and put aside for from twenty-four hours to three weeks. It is then again attached to the condenser. The bulb-tube *b* is then exhausted of air by means of the air-pump and connected to the condenser. Upon removing the lower pinchcock, the pressure in the apparatus is reduced. The water is now boiled for thirty minutes, the condenser being kept cold, and the gases dissolved in the water and the radium emanations are boiled out. The light being removed, cold distilled water is run into the flask through the short bent tube in *a*, and the whole of the gaseous contents of the flask and condenser are forced into the bulb-tube *b*. Meanwhile, the drying-tube and electroscope have been exhausted of air and the tube connected with the drying-tube, the electroscope charged, and the normal leak of the electroscope ascertained. The bulb-tube *b* is then connected to the drying-tube, and the pinchcock at the connected end removed.

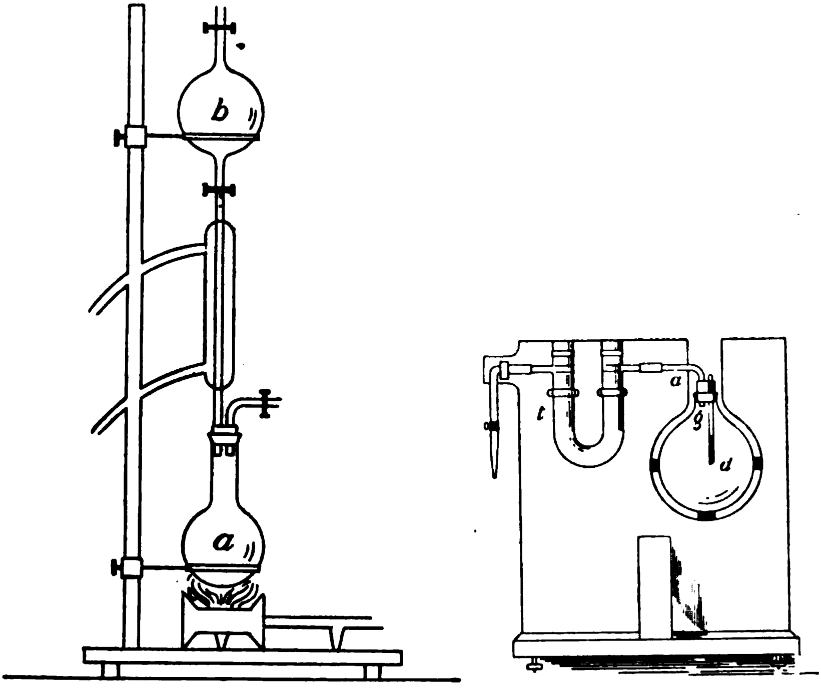

FIG. 15

Upon turning the tap on the drying-tube carefully, some of the gas is drawn into the electroscope. The remainder is forced in by pouring more water through *a* by means of a funnel and long tube, until the bulb-tube *b* is full of water. By this means all the gases evolved from the water are transferred to the electroscope. When the gases have all been discharged, a reading should be taken of the rate of collapse of the gold-leaf, and in three hours a second reading should be taken. If radium is present in the water, the rate of collapse will be found to have increased some 30 to 40 per cent. over the first reading. If actual measurements are to be attempted several precautions must be observed. The deflection of the gold-leaf at the commencement of the experiment should not exceed 30°. There should be no possibility of contamination by radio-active substances in the laboratory, and the water should remain clear during ebullition. This necessitates the addition of a little pure hydrochloric acid to the water in many cases. Notwithstanding this admonition, Joly recommends the placing of a little powdered steatite in the condenser, so that the condensed steam may carry it into the boiling flask and thus ensure the effervescent type of boiling.

Joly gives a Table by aid of which, after the electroscope has been calibrated, the amount of radium present in the water can be estimated; but for this and other details, his work should be consulted.

Ramsey, in his 'Report on the Mineral Waters of Bath,' gives the following Table:

| | | | |
|---|---|---|---|
| Radium in the water of the King's well | | 0·1387 | mlgr. per million litres |
| Niton (radium emanation) | in King's well | 1·73[1] | ,, ,, ,, |
| Niton ,, ,, | in Cross Bath | 1·19[1] | ,, ,, ,, |
| Niton ,, ,, | in Hettling Bath | 1·70[1] | ,, ,, ,, |
| Niton ,, ,, | gas from King's well | 33·65 | ,, ,, ,, |

He quotes MacOwen's results, as under, for the Buxton waters:

| | | |
|---|---|---|
| Hospital natural bath | 0·83 | mlgr. per million litres |
| Crescent pump room | 0·83 | ,, ,, ,, |
| Gentleman's natural bath | 1·10 | ,, ,, ,, |
| Natural gas from Buxton waters | 7·7 and 8·5 | ,, ,, |

---

[1] These figures are the weights of radium capable of forming the niton present in the waters and gas.

# CHAPTER XVIII

## TABLE OF ANALYSES OF WATER FROM VARIOUS GEOLOGICAL SOURCES

The ordinary sanitary analyses give very little information of value with reference to the saline constituents of waters from different sources. The more complete analysis, which includes the estimation of the more important acids and bases, or anions and cations, is often of value for sanitary purposes, and is imperative in determining whether waters are suitable for boiler and special manufacturing purposes. Records of such analyses must ultimately assist in the elucidation of many problems of considerable geological importance, especially those connected with the flow and distribution of underground waters.

A discussion of these questions is beyond the scope of this volume, but a number of examples of analyses of waters from the most important water-bearing strata are given here, as they will probably be useful, and may lead others to record analyses from these and other strata. With about two exceptions, all the analyses were made in my laboratories, and the exceptions were made by old assistants therein. A complete list of analyses of Essex deep well-waters will be given in the 'Geological Memoir on Essex,' which is now in course of preparation.

A study of the analytical results will show how difficult it often is to decide from what source a water has been obtained. It is not uncommon at certain examinations to submit the results of a partial analysis to a student and expect him to say from what geological source the water has been derived. Some of these analyses have been submitted to me, and I have been quite unable to determine the source. The fact is, that it is not generally known to what an extraordinary extent waters from the same geological formation vary in character

One of the most important causes is the character of the superimposed strata, and another the distance which the water has had to travel from the outcrop of the water-bearing stratum to the point at which the water is abstracted. These alone do not, however, account for all the variations. A water may issue from a fissure in one kind of rock, but may really be derived from rocks of an entirely different formation. In Essex many wells are bored into the chalk, but the whole of the water derived therefrom comes from the Thanet sand lying upon the chalk, and a well sunk in superficial sands and gravel may yield a hard or soft water, the character depending upon presence or absence of boulder clay in the vicinity. In some of our valleys the superficial springs on one side yield a fairly soft water, whereas on the other the water may be so impregnated with salts of calcium and magnesium as to be quite unfit for domestic purposes. In the latter case boulder clay will be found on the higher ground capping the gravel.

The great majority of the analyses given are of waters either used for public supplies, or which were examined to ascertain if they were suitable for this purpose. The hygienic character of most of the waters is indicated by the results of the estimation of the free and albuminoid ammonia, and of the oxygen absorbed in three hours at 37° C.

The silica has only occasionally been estimated, and the 'silica, &c.,' is merely the difference between the total of the saline constituents estimated and the total solids obtained by drying at 180° C. In some cases where the residues were exceedingly hydroscopic and could not be weighed, the residue was sulphated and the total solids calculated from the results obtained. In some waters, peaty matters account for the '&c.,' in others suspended clayey matter, which could not be removed by simple filtration, swells the amount, and, of course, any slight errors in the analyses also affect the quantity.

*Surface-waters from Various Districts, Nos.* 1–12.—These are chiefly on the coal measures. It is rarely necessary to make detailed analyses of such waters. Magnesium sulphate and sodium chloride and nitrate are the only constituents common to all. Calcium carbonate is absent in six out of the twelve, and these would act vigorously on lead, especially if they contained much $CO_2$ in solution. Nos. 4 and 5 had practically no action on that metal, whilst 1, 6, 7 and 11 had some action. The only one which contained iron was derived from near Bury, where there was an outcrop of ferruginous shale on the surface.

*River-waters, Nos.* 13–24.—These vary continually in character. The Thames water at Grays was examined because of suspected infiltration into the chalk in that locality. When pumping is excessive in the chalk quarries, magnesium chloride and sulphate make their appearance in the water, together with a much larger quantity of common salt. Bromides, not referred to in the analysis, can also be detected in the chalk-water when the chlorides markedly increase.

*Shallow Well Waters.*—Nos. 25 to 48 are chiefly from the drift. With the exception of Nos. 47 and 48, which are of alluvial origin, all the others were used for drinking and domestic purposes. No. 35, which is loaded with nitrates, is from a village pump, and has been in use for over twenty years to my knowledge, and so far as I can ascertain, notwithstanding the polluted character of the soil from which it is derived, it has had no marked effect upon the health of the consumers, and they have vigorously opposed, until quite recently, any effort to obtain a public supply of a better character. No. 36 contained more nitrates than any other water I have ever examined. It is a well at the bottom of a cottage garden, and is still in use. The soil is boulder clay. Nos. 47 and 48 are impregnated with sea-water, and, apparently, any nitrates the waters may have originally contained had been reduced to ammonia. Each well was sunk to ascertain if the water was usable for domestic and boiler purposes, but it certainly was not.

Nos. 49 to 56 are waters from the crags in Suffolk. With one exception they are exceedingly hard, and two are ferruginous. One acted vigorously on galvanised iron pipes, taking up a considerable amount of zinc. No. 49 is possibly affected by its proximity to the sea. If so, the original water must have contained sodium sulphate as did No. 50.

Nos. 57 to 60 were derived from the Bagshot beds, and these, apparently, may yield a hard or soft water. In Essex such waters contain little or no calcium carbonate, and have given rise to numerous cases of lead-poisoning, where lead-piping has been used for the construction of the pumps or for raising water from the wells. The well from which the Gosport sample was derived is over 200 feet deep, and the London clay is said to have been reached at about 206 feet. The only constituents common to all are sodium chloride and nitrate.

*Waters from the Lower London Tertiaries in Essex, Nos.* 61–96. —I have had no samples from any other county which could be definitely attributed to these strata. Almost certainly all are from the Thanet sands, as the upper beds contain so much clay that I am doubtful whether any water can be obtained from them. The possible exceptions are Nos. 76, 83, 91, 93 and 96, and all the information with reference to these wells is that they are sunk through the London clay and yield very little water. It is possible, therefore, that the bores terminate in the Blackheath, Woolwich, or Reading beds.

These exceptional waters contain no sodium carbonate, but varying amounts of magnesium sulphate, whereas all the waters undoubtedly derived from the Thanet sand contain sodium carbonate and no magnesium sulphate. The type is exceedingly characteristic, and the source of the constituents is discussed in a previous chapter.

Nos. 61, 62 and 63 are interesting, inasmuch as the well is the public source of supply of water to a hamlet, and the water is examined constantly. Analysis 61 may be said to represent the normal water prior to 1908, when I discovered that the chlorides had markedly increased and the water had become decidedly hard. As the well is within 100 yards of a tidal river, I suspected that some of the water had gained access, and the well was opened and examined. The examination of the well did not reveal any communication between the two, but the well was partially reconstructed, the bore-tube shelled, and the bore deepened some 20 feet. The result has been an improvement in the character of the water, but it has not become as soft as before, and the salt remains high. Other wells in the locality have also varied. When the well No. 64 was bored, the water yielded the results given, yet, when examined after the well had been in use a few weeks, it gave the result shown in No. 65.

Another remarkable change is shown in the water from the Tollesbury well. At a depth of 187 feet, the clay had been pierced and water rose in the bore-tube. The analysis of this water is given in No. 75. The boring was continued to 256 feet, and the water again examined, when it was found that the chlorides had increased and the sulphates had markedly decreased.

The Bulphan Fen water (No. 96) is certainly markedly affected by the sea, yet the water-level in the well is 18 feet above O.D. This bore does not overflow, but others near still overflow from pipes about 3 feet above the ground-level, 18 feet + O.D. The water from the overflowing wells is normal in character, that is, it contains sodium carbonate and sulphate, but the amount of salt is unusually low, 8·1 per 100,000.

The remarkable similarity between the Thanet sand waters and the waters Nos. 97 to 144, derived from the chalk in the same localities, leaves no room for doubt that the chalk-water in parts of Essex is really, in nearly all cases, derived from the Thanet sand and the other lower London tertiaries. Similar vagaries occur. Thus, the wells yielding the waters Nos. 140 and 141 are close together; yet one is a typical Thanet sand water and very soft, whilst the other contains magnesium sulphate and is very hard. When the results of a series of analyses of this kind are plotted out on the geological map, their importance becomes manifest.

The direction of the flow of the underground water can often be traced and the causes of the variations ascertained. The nature of the water which will be obtained by boring at any particular spot can be predicted with a fair amount of accuracy, and when details of the yield of other borings, the level of the water, &c., are recorded, the amount of water obtainable can also with confidence be predicted. Most of the hard waters in this series are found to be derived from wells near the outcrop of the chalk, where the water has not been fully softened by the action of the Thanet sands, referred to in a previous section. Curious anomalies are brought to light and open out fields for further investigation. For example, at Wyvenhoe the well No. 131 yields a water containing less salt than the well No. 132, yet the latter well is farther from the tidal estuary. The wells Nos. 101 and 102 are only about a mile apart, yet one is comparatively soft and the other very hard, and a line of demarcation can be drawn, upon one side of which the chalk yields a soft water, whereas upon the other side the yield is a hard water. On page 355 will be found the results of the analyses of water derived from the chalk at different depths, showing that the salinity increases with the depth. Several examinations were made during boring, which was carried down to the Layer Marney 1000 feet, but only two are recorded. They showed a gradual increase in the amount of salt present. The yield of the bore was very limited, not enough to supply a mansion and out-premises, and it was therefore abandoned. In other parts of Essex, where similar trials have been made, the same results have been obtained.

*Chalk-waters.*—Analyses 145 to 156 show that the water derived from the chalk under London is the same as that obtained in central and southern Essex. Near the Thames, however, there are many wells yielding water containing an admixture of tidal-water, showing that the Thames water gains access to the chalk. About this there can be no doubt, and the result will probably be that the multiplication of deep wells in the Metropolis, and the increased draught of water from the chalk, will result in a serious impregnation of the whole of the water-bearing stratum with sea-water.

I believe that evidence now available shows that this result can already be detected. On the south of the Thames the chalk yields water of most diverse character. At Bermondsey a well, recently sunk, yielded water which gave the following results :

| | | |
|---|---|---|
| Calcium carbonate | 33·75 | per 100,000 |
| Magnesium carbonate | 6·41 | " |
| Magnesium sulphate | 20·94 | " |
| Sodium sulphate | 28·30 | " |
| Sodium chloride | 31·34 | " |
| Sodium nitrite | ·36 | " |
| Silica, &c. | ·90 | " |
| | 122·0 | " |

The hardness is 60°. Other wells in the locality yield waters which are soft in comparison, and the depth of the chalk varies so much that an investigation of the area would be interesting. If time permits and sufficient information proves to be available, I may undertake the investigation. Such records as I possess chiefly refer to the north of the river, but apparently many wells have been sunk also on the south side, and some of the records may be available. Unfortunately some well-sinkers do not keep records, and others which I have had submitted to me are very unsatisfactory. Well-sinkers of repute keep accurate records and deposit them with the Geological Society at Jermyn Street, where they can be consulted. Records ought to be deposited with the Society of every well which pierces the superficial stratum, at the point where the well is sunk or the boring made.

Analyses 157 to 168 are of waters from wells on or very near the chalk outcrop, in Essex. These are of a totally different character to those just considered. Not one contains any sodium carbonate or sulphate, and calcium or magnesium nitrates are common. In fact, calcium and magnesium salts predominate, whereas, farther from the outcrop, sodium salts more or less completely replace them. At the Purfleet outcrop, tidal-water enters the chalk freely, and, by pumping in the chalk quarries, this influx is rapidly increased and the salt contents proportionately increase. Waters 165 and 166 are from the same well, 166 under fairly normal conditions, and 165 after pumping has been continuous and the water-level lowered. The effect of the influx of water from the river is most marked.

*Chalk-waters, Herts, Nos.* 169–180.—These may be said to be of a uniform type, but there are considerable variations in the quantity of saline matter present. Thus at Berkhampstead the water only contains 26·5 parts per 100,000, whereas elsewhere it may exceed 50 parts. Wells Nos. 177 to 180 are close together, yet the proportions of the saline constituents vary widely, and the hardness ranges from 26 to 38 degrees.

*Chalk-waters, Suffolk, Nos.* 181–192.—In this county the character of the water varies enormously in different districts, and the total saline constituents vary in the examples given from 31 to 530 parts per 100,000. The latter water, from a bore made at Shotley about one-eighth of a mile north of the tidal-river Stour, is evidently impregnated with tidal-water. The chalk is here covered by about 100 feet of clay and sand, and no water was obtained until a depth of 148 feet was reached, 111 feet below tide-level. In the Stour Valley water is entering the chalk, probably in several places, and its effect is evident on both sides of the river.

*Chalk-waters, Norfolk, Cambridge, Middlesex, and Rutland, Nos.* 193–204.—The variations in these areas do not appear to be nearly as great as in Suffolk, and the same remark applies to Nos. 205 to 216, chalk-waters derived from Surrey, Sussex, and Bucks. There are slight variations within a very limited radius, as is shown by the waters from deep wells in Guildford (Nos. 206 to 209).

*Chalk-waters, Dorset, Isle of Wight, and Wilts.*—Here again the variations observed are not very great, but the Swindon water contains an unusual amount of chalk in solution, and its hardness therefore exceeds that of any other sample. Nos. 221, 223, and 224 show that they are to a very slight degree affected by their proximity to the sea, by comparison with sample No. 222, which is entirely unaffected. In certain of these localities excessive pumping causes an increase of chlorides in the water, showing that the influx of sea-water is being accelerated.

*Chalk-waters, Hants, Nos.* 229–244.—Many of the wells from which these waters are derived are near the sea and show the effect of such proximity. The Foxbury well was originally a source of public supply, but the salinity increased so rapidly that the well and adits had to be abandoned. When examining the adits, I took samples from the various fissures through which water was entering, and found the one which was causing all the trouble (No. 234). When it was closed the same water issued from other fissures, and all attempts to cut it out ended in failure, hence the abandonment of the works. Well No. 237 is over 700 feet deep. When an excessive amount of chlorides is found in any stratum, it is useless sinking deeper in the hope of obtaining a better water from the same stratum, as invariably the salinity increases with the depth. Enormous sums of money are wasted annually in useless borings, all for want of advice from a disinterested and competent person. Of course, if another water-bearing stratum can be reached, there may be hope of obtaining a better water, but the probabilities are not great. The Woolaston boring (near Southampton) illustrates this. At a depth of 450 feet and above the chalk, water was obtained of 45° of hardness and containing 63 parts of chlorine per 100,000. The boring was continued, therefore into the chalk to a total depth of 870 feet, when the hardness was found to have increased to 50° and the chlorine to 84 parts per 100,000. The water was also discoloured and ferruginous.

*Chalk-waters, Kent, Nos.* 245–262.—Calcium and magnesium nitrates are present in many of these waters, doubtless derived from manurial matter by oxidation. As might be expected, some of the wells near the coast, or Thames estuary, show the infiltration of tidal-water. At Herne Bay (No. 262) the chalk is covered with 210 feet of tertiaries, and though the boring goes 70 feet into the chalk, there is no doubt that the whole of the water is derived from the Thanet sands. The potassium salts present in this sample were estimated, as the flame reaction indicated that more were present than in Essex Thanet sand waters. The gases in solution and the free and semi-combined carbonic acid were also determined, and it was found that the $CO_2$ present was just sufficient to convert all the carbonates into bicarbonates, no $CO_2$ existing in a free condition. This is the case with all the Thanet sand-waters yet examined.

*Chalk-waters, Various Sources, Nos.* 263–276.—Note the comparatively large amount of salt in the waters from the chalk in S.E. Yorkshire, and that two out of the three samples were ferruginous. Wells Nos. 271 and 272 are fairly close together, but No. 271, which is a deeper well and on much higher ground, contains much more salt than 272. Few successful borings appear to have been made in this locality into the chalk; either the amount of water obtained has been very limited, or the quality unsatisfactory. The water from wells Nos. 275 and 276 are said to be chiefly derived from the sands resting on the chalk. One resembles the water from the Thanet sands in the London basin, but the other appears to be a true chalk-water.

*Greensand Water, Nos.* 277–295.—It does not appear possible to distinguish between water derived from the upper and the lower Greensand, and waters from both sources vary greatly in character. Save that they are often ferruginous, they differ little from chalk-waters.

Well No. 277 is said by experts to be a Greensand water, but it certainly has all the characteristics of a Thanet sand water. The well is near Skegness, six miles from the sea, and the water overflows. Well No. 282 is 1585 feet deep. It contains a considerable amount of salt and sufficient iron to render it very unsightly a few minutes after it is drawn. The superficial waters, as the spring at Shere, No. 281, contain very small amounts of chlorides, and are not very hard. In certain areas sands of different colours are met with, separated by beds of clay, and yielding waters of different characters. In the Wing boring, different samples examined varied in hardness from 20° to 55°. The water from the Linslade boring varies in character, the hardness on one occasion being only 25°.

*Hastings Sands Water, Nos.* 296–300.—These sands almost invariably yield a ferruginous water, and the variations in character are very considerable. The boring at Stye Place is 830 feet deep, and water in percolating to this depth has evidently passed through some zeolitic stratum, which has substituted sodium for the calcium and magnesium in the salts originally present in the water. The Purbeck beds, lying immediately below the Hastings sands, yield very little water. The only sample, which I have examined, was from the Purbeck beds, near Swanage. Water entering at different points differed in hardness, but all were very hard, and contained considerable quantities of calcium carbonate and sulphate.

*Water from the Upper and Middle Oolite, Nos.* 302–307 : *Lower Oolite, Nos.* 308–324.—About half the samples examined contain sodium carbonate, some in large proportions. Others contain excessive amounts of sodium chloride, and in the Woodhill Spa water this is associated with much magnesium chloride, which would have suggested some connection with tidal-water had the well been near the sea. As it also contains bromides, bromates, and iodides, and is a medicinal and not a potable water, it cannot be compared with the samples of potable water. Most of the waters also contain sodium sulphate. The hardness varies from 6½° to 40°. The variations are exceedingly marked, and there is no definite characteristic, but the majority contain both sodium sulphate and carbonate, as do the Thanet sand waters ; but, unlike these, the Oolite waters are, as a rule, very hard, and the hardness is chiefly of the temporary character.

*Water from Lias, Nos.* 325–329.—These represent waters from Somerset, Lincoln, Gloucester, and Yorkshire. All contain magnesium sulphate and are very hard. In some the permanent hardness exceeds the temporary. No. 326 is from a 95-feet boring into the Lower Lias, and Mr. Preston, F.G.S., informed me that it comes from the ironstone band in the zone of *Ammonites varicostatus.*

*Water from the New Red Sandstone, Nos.* 330–369.—These derived from various counties. The variations observed are enormous. Many are excessively hard, a few comparatively soft. All contain magnesium salts ; some in small quantity, others in large quantity. No. 330 was derived from a boring 1800 feet deep, and no record appears to have been kept of the strata passed through. My informant said that the boring passed through three beds of coal and three of fire clay. That at 870 feet water was met with; and at 1800 feet boring ceased because no more water was obtained. He adds: 'There is from ½ to 1 mile of the New Red Sandstone which contains barium.' As the coal measures are below the Lias, it is difficult to see how New Red Sandstone could have been met with in this boring. This sandstone does outcrop near Ilkestone. I am inclined to think the Old Red Sandstone is intended. In South Lancashire the water yielded varies in character; in sinking one of the wells near Warrington, water entered at three different points, and these waters varied much in hardness. I expressed the opinion that by cutting out the two upper sources a water of good character would be obtained, and this proved to be the case, a water of 17° to 18° of hardness being the result. All the New Red Sandstone waters contain appreciable quantities of magnesium salts, some as carbonates, others as sulphates, and many as chlorides. The amount of sodium chloride is usually small, but in some cases it is very excessive. The Avonmouth water (No. 339) is from a boring made to obtain a potable water. It was 73 feet deep, all in the Keuper sandstone. Sea-water has undoubtedly gained access to the stratum here. In Notts an abundance of good water is obtained from this formation, but in most cases both the temporary and permanent hardness are high, and sometimes the water contains an unusual amount of magnesium chloride, a not unimportant constituent if the water is to be used for boiler purposes. The Yorkshire waters from this formation also vary greatly, and possibly by plotting these on the geological map the cause of the variation could be discovered. None of them contain any unusual amount of salt or of magnesium chloride. Several of them are markedly ferruginous. Sections of most of these wells are given in the M.O.H.'s report on the water supplies from the New Red Sandstone in the West Riding, 1903. No. 363 may be said to represent the normal unpolluted water from the sandstone at Crowle, Lincs. No. 364 from the public pump in the Market Place is loaded with nitrates, and shows in a remarkable degree the effect of the population living upon this pervious stratum.

No. 365 is from the celebrated Lincoln boring, undertaken under the direction of Mr. Percy Griffiths. Not a drop of water was met with until the marls were pierced at a depth of 1561 feet. Water then rose and overflowed at the surface, at the rate of 180,000 gallons per diem. The temperature of the water remained constant at 77° F. The sample examined was taken when the boring had reached 2120 feet. The boring was, I believe, stopped at 2200 feet. To what extent the water may have varied at different depths I do not know, but six months after I had examined the first sample the total solids had fallen from 410 to 222 parts per 100,000. Enough water was not received to make a very full analysis. From an analysis submitted to me of a sample taken some time before the boring was stopped, the total solids were 555 parts per 100,000. The Gainsborough bores (Nos. 367, 368), which are 1352 and 1515 feet deep respectively, yield waters of a very different character, but the new and deeper bore (No. 318) yields much the better water, since it contains far less sulphate of calcium. In Staffordshire a boring made to obtain a supply of potable water yielded a water containing a large quantity of calcium sulphate (No. 369).

*The Coal Measures, Nos.* 370–390.—Here again an extraordinary variety of waters is obtained, all hard, some excessively hard. A number of samples were collected from used and disused coal mines in the Rochdale neighbourhood. Most of them were ferruginous, but few of them were excessively hard. Some were of excellent quality, and the softest contained sodium carbonate, and were well fitted for all domestic purposes. With two exceptions, all waters from the Coal Measures contained sodium sulphate, and these exceptions may possibly be Millstone Grit waters : one is from a spring in the Rhymney Valley, and the other from the Severn Tunnel.

Nos. 385 to 389 are from coal mines in West Gloucester. One mine yields a most variable water, the hardness rising with the amount of water pumped. It is noteworthy that when magnesium sulphate is absent, sodium sulphate is present in much larger quantity than in the waters in which magnesium sulphate is present. There is a clear indication of a zeolitic action substituting sodium for magnesium in the sulphate.

*Millstone Grit Waters, Nos.* 391–394.—No. 391 is from a boring 265 feet deep, the others are surface-waters from this formation. Obviously this compact rock yields comparatively little saline matter to the water penetrating it, calcium carbonate being chiefly dissolved. A little sodium carbonate is present in the water from the deep bore.

*Mountain Limestone Waters, Nos.* 395–404.—The Trefil brook is fed by springs and surface-water from this formation. At one point in its course, most of the water disappears through fissures, and it again emerges as a spring (No. 396) about half a mile lower down the valley. In its course it appears to have taken up nothing from the rocks which it has travelled. The waters from the Millstone Grit formation (Nos. 393, 394) come from the opposite side of the valley and enter the Trefil brook just above the spring. The difference in the character of the brook waters from the two formations is decisively marked.

The Pontypool water is derived from headings driven into the fissured limestone. The Bakewell water (No. 390) arises from a spring in this formation, but the temperature is said to be distinctly higher than that of other waters in the locality. It may therefore have its origin in an entirely distinct formation, which would account for the presence of the calcium and magnesium sulphates.

The waters from Ireland are all from wells of moderate depth, Nos. 399 to 404 being derived from the Mountain Limestone, whilst No. 405 is derived from the Old Red Sandstone.

*Old Red Sandstone Waters, Nos.* 405–406.—No. 406 is the only sample I have had submitted, which comes from a deep well in this formation. It is 376 feet deep, and the water overflows at the surface. A well is sunk through all the more superficial beds, 126 feet in thickness, and tubed into the sandstone. The sample was taken from the bore-tube after the well had been pumped dry, so that it is, undoubtedly, derived entirely from this formation. It is a comparatively soft water of excellent character.

*Water from Older Rocks, Nos.* 407–410.—Note the resemblance between the Llandrindod water and that from the boring at Kelso. In making the Kelso boring a very good water was first obtained ; but upon piercing the calciferous limestone to a depth of 200 feet, this highly saline water (No. 407) broke in and rendered the boring useless. A boring at Floor's Castle, near Kelso, in the same formation, yields an excellent water. The lime and magnesium salts have practically disappeared, having been replaced by sodium salts. The result is a water of only 2° of hardness.

Waters 414 to 419 are all from Africa, and 419 from Australia. The water from Damaraland, German S.W. Africa, was submitted for examination because it was alleged to have a poisonous effect upon cattle, and the presence of arsenic was suspected. None could be found in it. The well is 5 metres in depth, the section being 1 metre lime tuffa, 2 of greenish clay containing fragments of bones, 3 of round stones, and 1·7 into red clay. The clay contains a good deal of fine mica, and the well could not be sunk deeper on account of the large amount of poisonous gas (? $CO_2$) given off. The agent of the estate wrote as follows : 'The water in the well has a peculiar taste, and acts as a purgative. The cattle on the farm get fat and seem to have a desire for water all the time. Mr. S—— has lost several head of cattle here, and he ascribes it to poisoning ; the cattle do well for six months at a time, but they have to be changed to some other farm for a few months. Mr. S—— says that at one of the old "puitz" it is no seldom occurrence that they find up to 40–50 dead birds, which have been poisoned by the water. It may possibly be a case of arsenical poisoning.'

The water contained a good deal of mica in suspension, and this might account for intestinal irritation. Nothing of a poisonous character could be found in it. An accumulation of $CO_2$ at the head of the old 'puitz' would account for the death of the birds.

The Zanzibar waters are all from springs. These were examined to ascertain which was most suitable for a supply of water to the city. The very silicious water was undoubtedly the best.

The Morocco waters are derived from wells sunk to obtain potable waters for an estate. Not only were they loaded with saline matter, but they also contained enormous amounts of nitrates and much organic matter.

The Singapore water (No. 418) is from a hot spring, and the water contained 0·3 part of lithium carbonate per 100,000.

The water from Australia was submitted, to ascertain if it would be so treated as to fit it for boiler and drinking purposes. It was bored by the Midland Railway Co. It is of a curious character, said to come from a limestone formation, and the presence of so much sodium salts suggests a resemblance to the Essex Thanet sand waters, but it differs from them in being excessively hard.

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### SURFACE WATERS

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Nr. Bury, Lancs | Nr. Bury, Lancs | Nr. Bury, Lancs | Aberdeenshire | Tavistock, Devon | Colwyn, N. Wales | Nr. Wakefield, Yorks | Nr. Oldham | Nr. Oldham | Nr. Oldham | Pontypool | Chesendon Lancs |
| Calcium Carbonate | ·8 | — | — | 2·25 | 2·0 | ·9 | ·45 | — | — | — | 1·4 | — |
| Calcium Sulphate | 3·2 | 3·9 | 4·1 | 1·0 | ·7 | — | 3·1 | 4·3 | 4·0 | 9·35 | — | 2·2 |
| Calcium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate | — | — | — | — | — | — | — | — | — | — | ·1 | — |
| Magnesium Sulphate | 2·8 | 2·35 | 2·3 | 1·0 | ·25 | ·25 | 1·35 | ·25 | ·2 | ·5 | ·85 | 1·5 |
| Magnesium Chloride | — | — | — | ·8 | — | — | — | — | — | — | — | — |
| Sodium Carbonate | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate | — | — | — | — | — | — | — | — | — | — | 1·25 | — |
| Sodium Chloride | 1·8 | 2·15 | 2·3 | 2·3 | 3·3 | 1·3 | 1·8 | 2·15 | 2·05 | 2·5 | 2·0 | 2·5 |
| Sodium Nitrate | ·35 | ·4 | ·4 | 3·0 | ·75 | ·05 | ·15 | ·4 | ·15 | 1·4 | ·05 | ·95 |
| Silica, &c. | Fe trace<br>3·45 | 2·5 | 1·4 | 3·15 | ·5 | ·3 | 1·15 | ·3 | ·8 | ·95 | ·45 | ·85 |
| Total | 12·4 | 11·3 | 10·5 | 13·5 | 7·5 | 2·8 | 8·0 | 7·4 | 7·2 | 14·7 | 6·1 | 8·0 |
| Hardness | 6° | 6° | 5° | 5° | 4° | 1½° | 4½° | 5° | 5° | 10° | 2½° | 3½° |
| Free Ammonia | ·003 | ·002 | ·003 | ·006 | ·002 | ·002 | ·005 | ·002 | ·003 | — | ·0005 | ·036 |
| Albuminoid Ammonia | ·010 | ·012 | ·006 | ·006 | ·005 | ·004 | ·012 | ·005 | ·004 | — | ·001 | ·004 |
| Oxygen absorbed | ·068 | ·084 | ·160 | ·040 | ·050 | ·015 | ·060 | — | — | — | ·016 | ·068 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### RIVER WATERS

| Source | 13 New River | 14 Thames, Staines | 15 Thames, Slough | 16 Thames, Grays | 17 Lea, West Ham | 18 Dee, above Chester | 19 Stour, Nr. Bournemouth | 20 Witham, Nr. Lincoln | 21 Welland, Nr. Grantham | 22 Blackwater, Essex | 23 Seine, above Paris | 24 Svarta, Sweden |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 15·3 | 19·8 | 18·0 | 16·3 | 23·75 | 8·5 | 23·2 | 18·7 | 19·8 | 24·55 | 18·4 | 3·5 |
| Calcium Sulphate . . | — | 4·0 | 4·95 | 71·4 | 10·05 | — | 1·55 | 12·0 | 8·15 | 3·1 | 1·85 | — |
| Calcium Chloride . . | — | ·8 | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | — | — | — | — | — | ·4 | — | 2·55 | — | — | — | ·55 |
| Magnesium Sulphate . | 2·0 | — | 1·65 | 129·5 | 5·5 | 3·4 | ·75 | — | 3·05 | 3·15 | 1·0 | — |
| Magnesium Chloride . | — | 1·6 | ·6 | 154·8 | 1·2 | — | ·4 | — | 1·6 | — | — | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | 1·75 | — | — | — | — |
| Sodium Sulphate . . | — | — | — | KCl<br>41·0 | — | 1·6 | — | — | — | ·45 | — | 1·0 |
| Sodium Chloride . . | 3·0 | 4·9 | 2·55 | 1391· | 5·1 | 3·6 | 2·8 | 3·5 | 2·65 | 6·9 | 2·0 | 1·3 |
| Sodium Nitrate . . | ·7 | 5·3 | 2·05 | 2·5 | 3·4 | ·1 | 2·1 | ·2 | 1·2 | 2·3 | 1·1 | ·1 |
| Silica, &c. . . . | ·6 | 1·6 | 3·4 | 47·5 | 2·0 | ·9 | 1·0 | ·7 | ·55 | ·55 | ·45 | ·65 |
| Total . . | 21·6 | 38·0 | 33·2 | 1854·0 | 51·0 | 18·5 | 31·8 | 39·4 | 37·0 | 41·0 | 24·8 | 7·1 |
| Hardness . . . | 16° | 26° | 22° | — | 30° | 12° | 21° | 29° | 25° | 23° | 20° | 3·5° |
| Free Ammonia . . | ·000 | ·006 | ·010 | — | ·48 | ·010 | ·011 | ·001 | ·006 | ·006 | ·008 | ·005 |
| Albuminoid Ammonia . | ·007 | ·007 | ·023 | — | ·066 | ·019 | ·020 | ·001 | ·020 | ·018 | ·011 | ·020 |
| Oxygen absorbed . . | ·100 | ·128 | ·325 | — | ·60 | ·245 | ·177 | ·007 | ·174 | ·148 | ·090 | ·280 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### 25–27 Boulder Clay Waters. 28–36 Post-tertiary Gravel and Sand. All Shallow Wells

| | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | S. Hanningfield, Essex | Gt. Waltham, Essex | Epping, Essex | Tonbridge, Kent | Longham, Hants | Lutterworth, Leicester | Copford, Essex | Clacton, Essex | Gt. Bentley, Essex | Coggeshall Essex | Tollesbury Essex | Broomfield, Essex |
| Calcium Carbonate . . | 23·4 | 34·5 | 15·5 | 17·2 | 22·05 | 27·6 | 28·8 | 6·5 | 2·5 | 29·3 | 14·0 | 20·5 |
| Calcium Sulphate . . | 17·6 | — | 12·95 | 5·8 | 2·4 | 12·9 | 2·6 | 5·4 | 8·8 | 2·05 | 31·3 | 54·5 |
| Calcium Chloride . . | 14·1 | — | — | — | — | — | — | — | — | — | — | 24·1 |
| Magnesium Carbonate . | — | ·85 | — | — | — | — | — | — | — | — | — | — |
| Magnesium Sulphate . | — | 8·25 | — | 4·0 | ·4 | 0·65 | 3·5 | 6·5 | 3·75 | 3·25 | 5·5 | — |
| Magnesium Chloride . | 11·5 | — | 4·2 | — | ·95 | 1·85 | — | — | 1·7 | — | 7·5 | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | 7·55 | — | — | — | — | — | 2·7 | — | 5·0 | — | — |
| Sodium Chloride . . | 24·6 | 3·65 | 1·15 | 6·1 | 2·1 | 1·35 | 5·3 | 12·5 | 4·3 | 5·1 | 17·5 | $Ca2NO_3$<br>4·9 |
| Sodium Nitrate . . | 3·7 | 1·25<br>$H_2S$ tr. | 7·5 | 1·7 | 2·1 | 3·4 | 1·65<br>$ZnCO_3$<br>2·1 | 5·4 | 5·6 | 4·9 | 22·8<br>$KNO_3$<br>17·0 | $Mg2NO_3$<br>18·5<br>45·5<br>$KNO_3$<br>5·85 |
| Silica, &c. . . . | 3·1 | 1·95 | ·7 | 2·2 | ·5 | ·3 | 1·75 | 3·0 | ·35 | — | 4·7 | 6·15 |
| Total . . | 98·0 | 58·0 | 42·0 | 37·0 | 30·5 | 48·05 | 45·7 | 42·0 | 27·0 | 49·6 | 120·3 | 180·0 |
| Hardness . . . | 46° | 30° | 30° | 26° | 21° | 31° | 27° | 16° | 16° | 33° | 41° | abt. 150° |
| Free Ammonia . . | ·004 | ·016 | ·000 | ·001 | ·002 | ·001 | ·000 | ·003 | ·001 | ·000 | ·000 | 0·012 |
| Albuminoid Ammonia . | ·014 | ·008 | ·004 | ·004 | ·007 | ·006 | ·011 | ·009 | ·006 | ·005 | ·013 | 0·035 |
| Oxygen absorbed . | ·240 | ·202 | — | ·030 | ·081 | ·020 | ·064 | ·032 | ·036 | ·008 | ·173 | 0·400 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### SHALLOW WELL WATERS

| Source | 37<br>Tiptree, Essex | 38<br>Lexden, Essex | 39<br>Chelmsford, Essex | 40<br>Felstead, Essex | 41<br>Kelvedon, Essex | 42<br>Danbury, Essex | 43<br>Southminster, Essex | 44<br>Woodham Walter, Essex | 45<br>Gt. Waltham, Essex | 46<br>Gt. Baddow, Essex | 47<br>Millwall London, | 48<br>East Ham Essex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 5·0 | 2·5 | 30·0 | 33·3 | 17·5 | 2·5 | 1·0 | 5·5 | 27·7 | 4·0 | 39·7 | 70·0 |
| Calcium Sulphate . . | 2·7 | 3·0 | 5·4 | 12·3 | 8·5 | 5·95 | 3·4 | 2·4 | 10·2 | 10·2 | 49·0 | 25·2 |
| Calcium Chloride . . | — | 4·4 | — | 2·4 | — | ·95 | 3·0 | — | 2·5 | — | ·8 | — |
| Magnesium Carbonate . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Sulphate . | 1·0 | — | 3·0 | — | 2·5 | — | — | 1·0 | — | ·75 | — | 26·5 |
| Magnesium Chloride . | ·8 | 1·7 | 1·2 | 2·7 | — | 2·15 | 2·3 | ·8 | 1·1 | 3·35 | 66·5 | 22·7 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Chloride . . | 2·5 | — | 3·9 | 3·1 | 5·4 | ·65 | - | 2·15 | — | 1·5 | 334·6 | 181·5 |
| Sodium Nitrate . . | 3·95 | 3·0 | 4·9 | 4·9 | 5·7 | 4·8 | 8·5 | 2·75 | 4·8 | 6·7 | — | — |
|  |  | $Mg2NO_3$<br>3·6 |  |  |  |  |  |  |  |  | $FeCO_3$<br>13·1 |  |
| Silica, &c. . . . | ·55 | ·8 | ·6 | 1·3 | ·4 | ·5 | ·3 | ·4 | ·7 | ·3 | 6·3 | ·6 |
| Total . . | 16·5 | 19·0 | 49·0 | 60·0 | 40·0 | 17·5 | 18·5 | 15·0 | 47·0 | 26·8 | 510·0 | 326·5 |
| Hardness . . . | 8½° | 13½° | 32° | 40° | 23° | 10° | 12° | 10° | 38° | 18° | 131° | 150° |
| Free Ammonia . . | ·002 | ·001 | ·001 | ·000 | 1·12 | ·001 | ·004 | ·001 | ·000 | ·001 | loaded | loaded |
| Albuminoid Ammonia . | ·010 | ·002 | ·006 | ·003 | ·007 | ·002 | ·002 | ·002 | ·002 | ·002 | ·018 | ,, |
| Oxygen absorbed . . | ·052 | ·027 | ·028 | ·028 | ·063 | ·020 | ·016 | ·016 | ·020 | ·020 | — | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

PLIOCENE CRAGS, 49–56. UPPER EOCENE, BARTON AND BAGSHOT SANDS, 57–60

| | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 60A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Aldeburgh, Suffolk | Ipswich, Suffolk | Southwold, Suffolk | Nr. Southwold, Suffolk | Nr. Southwold, Suffolk | Woodbridge, Suffolk | Yoxford, Suffolk | Yoxford, Suffolk | Barton, Hants | Gosport, Hants | Barnet Hill, Surrey | Brentwood, Essex | Cowes, I. of Wight |
| Calcium Carbonate . | 23·3 | 41·4 | 27·3 | 20·8 | 5·6 | 33·3 | 28·3 | 33·8 | 15·8 | 11·35 | 7·5 | — | 14·75 |
| Calcium Sulphate . | 10·2 | — | 5·5 | 3·4 | 6·1 | 15·3 | 6·55 | — | 1·0 | — | 3·1 | 3·4 | — |
| Calcium Chloride . | — | — | 2·5 | 3·3 | 4·6 | — | — | — | — | — | 1·1 | — | — |
| Magnesium Carbonate | — | ·5 | — | — | — | — | — | — | — | 2·25 | — | — | 3·7 |
| Magnesium Sulphate. | 4·0 | 2·5 | — | — | — | 2·15 | 1·45 | 3·15 | 2·0 | ·75 | — | 1·45 | — |
| Magnesium Chloride . | — | — | 1·0 | 1·6 | 1·15 | ·8 | 1·35 | — | — | — | ·8 | — | — |
| Sodium Carbonate . | — | — | — | — | — | — | — | — | — | — | — | — | 1·4 |
| Sodium Sulphate . | — | 5·1 | — | — | — | — | — | — | 1·2 | 4·45 | — | 1·85 | 5·55 |
| Sodium Chloride . | 42·2 | 12·2 | 1·25 | 1·0 | ·55 | 8·7 | 6·0 | 5·95 | 6·45 | 14·85 | 1·1 | 1·15 | 3·3 |
| Sodium Nitrate . | 8·0 | ·5 | 4·15 | 4·2 | 6·5 | 1·9 | ·15 | ·25 | 1·4 | ·65 | 2·4 | 1·45 | ·4 |
| | | ZnCO$_3$<br>3·8 | | | | FeCO$_3$<br>trace | | FeCO$_3$<br>2·3 | | | | | |
| Silica, &c. . . | 2·0 | — | ·1 | 1·2 | 1·0 | ·85 | 2·2 | ·35 | 1·65 | ·7 | ·8 | ·6 | ·1 |
| Total . . | 89·7 | 66·0 | 41·8 | 35·5 | 25·5 | 63·0 | 46·0 | 45·8 | 29·5 | 35·0 | 16·8 | 9·9 | 29·2 |
| Hardness . . | 26° | — | — | 26° | 18½° | 43° | 34° | 36° | 18° | 16° | 12° | 4·3° | 19° |
| Free Ammonia . . | ·000 | — | — | ·001 | ·001 | ·002 | ·000 | ·008 | — | ·032 | — | ·000 | ·086 |
| Albuminoid Ammonia | ·009 | — | — | ·005 | ·003 | ·003 | ·013 | ·014 | — | ·002 | — | ·004 | ·002 |
| Oxygen absorbed . | ·092 | — | — | ·024 | ·040 | ·024 | ·072 | ·080 | — | ·107 | — | ·048 | — |

## RESULTS OF WATER ANALYSIS, IN PARTS PER 100,000

### Lower London Tertiaries. Deep Wells

|  | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Hey-bridge, Essex, 1900 | Hey-bridge, Essex, 1908 | Hey-bridge, Essex, 1909 | Hey-bridge Hall, Essex | Hey-bridge, Essex | Hey-bridge, Essex | Maldon, Essex | Maldon, Essex | Maldon, Essex | Maldon, Essex | Maldon, Essex | Maldon, Essex |
| Calcium Carbonate . . | 3·25 | 9·0 | 6·3 | 6·9 | 3·0 | 3·75 | 1·75 | 2·5 | 2·25 | 15·25 | 2·25 | 3·2 |
| Calcium Sulphate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 1·9 | 5·5 | 3·8 | 5·25 | 2·45 | 3·45 | 2·1 | 1·8 | 2·45 | 6·3 | 2·05 | 1·7 |
| Magnesium Sulphate . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Chloride . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate . . | 34·75 | 25·1 | 17·6 | 28·75 | 31·85 | 32·5 | 37·4 | 36·3 | 36·8 | 11·75 | 38·0 | 36·5 |
| Sodium Sulphate . . | 16·3 | 16·8 | 11·8 | 19·25 | 13·7 | 15·15 | 15·0 | 7·7 | 9·75 | 18·95 | 10·8 | 8·7 |
| Sodium Chloride . . | 69·8 | 128·8 | 90·2 | 155·1 | 85·8 | 90·0 | 60·0 | 83·1 | 83·0 | 71·45 | 60·7 | 80·1 |
| Sodium Nitrate . . | ·2 | ·4 | — |  | ·55 | ·25 | ·4 | ·15 | ·4 | 4·8 | ·25 | — |
|  |  |  |  | FeCO$_3$ 1·0 |  | Fe trace |  |  |  |  |  |  |
| Silica, &c. . . . | 1·3 | ·4 | ·6 | 1·15 | — ·35 | ·9 | 2·35 | ·95 | ·35 | 2·0 | 0·95 | 1·8 |
| Total . . | 127·5 | 186·0 | 130·3 | 217·4 | 137·0 | 146·0 | 119·0 | 132·5 | 135·0 | 130·5 | 115·0 | 132·0 |
| Hardness . . . | 5° | 21° | 14° | 13° | 7° | 10° | 4° | 7° | 6° | 17° | 8° | 6° |
| Free Ammonia . . | ·056 | ·120 | ·025 | ·120 | ·001 | ·132 | ·010 | ·066 | ·004 | ·012 | ·072 | ·003 |
| Albuminoid Ammonia . | ·002 | ·004 | ·003 | ·002 | ·000 | ·006 | ·002 | ·003 | ·004 | ·010 | ·002 | ·003 |
| Oxygen absorbed . . | ·088 | ·092 | ·050 | — | ·048 | — | — | ·028 | ·051 | ·055 | ·036 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Lower London Tertiaries. Deep Wells

|  | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Tollesbury, 187 ft. | Tollesbury, 256 ft. | Burnham, Essex | Althorne, Essex | Mundon, Essex | Foulness Island, Essex | Foulness Island, Essex | Foulness Island, Essex | Foulness Island, Essex | Mersea Island, Essex | Mersea Island, Essex | Mersea Island, Essex |
| Calcium Carbonate | 5·25 | 4·25 | 3·25 | 29·3 | 3·0 | 2·15 | 10·25 | 2·25 | 7·0 | 4·5 | 39·0 | 3·2 |
| Calcium Sulphate | — | — | — | 7·6 | — | — | — | — | — | — | — | — |
| Calcium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate | 2·15 | 1·95 | 2·75 | — | 1·4 | 1·0 | 6·9 | 1·0 | 3·8 | 1·05 | 4·55 | 2·4 |
| Magnesium Sulphate | — | — | — | 42·5 | — | — | — | — | — | — | 32·0 | — |
| Magnesium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate | 32·45 | 35·9 | 32·7 | — | 37·1 | 30·1 | 14·95 | 30·0 | 23·2 | 33·85 | — | 34·3 |
| Sodium Sulphate | 40·5 | 12·1 | 9·4 | 59·2 | 12·0 | 10·8 | 18·95 | 12·0 | 17·5 | 23·1 | 15·7 | 21·3 |
| Sodium Chloride | 118·9 | 123·7 | 61·5 | 49·3 | 62·0 | 75·0 | 141·5 | 77·0 | 121·4 | 128·0 | 54·9 | 126·1 |
| Sodium Nitrate | ·35 | ·35 | ·0 | ·9 | ·1 | ·55 | ·85 | ·4 | 0·6 | ·45 | ·2 | ·55 |
|  |  | Fe trace |  |  |  |  |  |  | Fe trace |  | Much organic matter |  |
| Silica, &c. | ·4 | ·75 | 0·4 | 1·2 | ·4 | ·4 | ·6 | ·35 | 2·0 | ·05 | 9·95 | 2·15 |
| Total | 200·0 | 179·0 | 110·0 | 190·0 | 116·0 | 120·0 | 194·0 | 123·0 | 175·50 | 191·0 | 156·30 | 190·0 |
| Hardness | 10½° | 10° | 6° | 88° | 6° | 6° | 31° | 5° | 20° | 7° | 40° | 7° |
| Free Ammonia | ·145 | ·120 | ·050 | ·003 | ·040 | ·040 | ·010 | ·001 | ·144 | ·015 | ·012 | — |
| Albuminoid Ammonia | ·004 | ·006 | ·002 | ·008 | ·003 | ·002 | ·003 | ·002 | ·002 | ·004 | ·028 | — |
| Oxygen absorbed | ·252 | ·236 | ·043 | ·140 | ·055 | ·064 | ·040 | ·040 | ·044 | ·064 | ·209 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### LOWER LONDON TERTIARIES. DEEP WELLS

| | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Writtle, Essex | Broomfield, Essex | Chelmsford, Essex | Shoeburyness, Essex | Shoeburyness, Essex | Canewdon, Essex | Abberton, Essex | Great Saling, Essex | Waltham Abbey, Essex | Osea Island, Essex | Braintree, Essex | Bulphan, Essex |
| Calcium Carbonate . . | 2·0 | 1·8 | 2·0 | 4·0 | 1·7 | 1·5 | 16·85 | 5·9 | 9·5 | 7·9 | 1·85 | 29·3 |
| Calcium Sulphate . . | — | — | — | — | — | — | — | — | 44·2 | — | — | 114·9 |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | ·5 | 1·05 | 1·75 | ·85 | ·85 | 1·75 | 4·75 | 5·2 | — | 3·85 | 1·55 | — |
| Magnesium Sulphate . | — | — | — | — | — | — | 11·5 | — | 44·4 | — | — | 362·5 |
| Magnesium Chloride . | — | — | — | — | — | — | — | — | — | — | — | 45·5 |
| Sodium Carbonate . . | 32·65 | 35·0 | 31·4 | 24·05 | 27·8 | 32·6 | — | 16·4 | — | 23·35 | 28·5 | — |
| Sodium Sulphate . . | 13·6 | 8·9 | 14·2 | 10·35 | 8·3 | 11·1 | 208·4 | 10·2 | 99·5 | 17·3 | 26·3 | — |
| Sodium Chloride . . | 45·85 | 56·4 | 54·8 | 55·3 | 55·1 | 56·9 | 136·0 | 37·4 | 42·2 | 50·5 | 35·6 | 231· |
| Sodium Nitrate . . | ·4 | ·2 | ·1 | trace | ·25 | ·2 | — | ·4 | ·6 | — | ·2 | 1·5 |
| Silica, &c. . . . | 1·5 | 1·15 | ·75 | ·45 | ·5 | 1·95 | ·5 | ·5 | 2·6 | 1·6 | 1·0 | Water of hydration, &c.<br>33·3 |
| Total . . | 96·5 | 104·5 | 105·0 | 95·0 | 94·5 | 106·0 | 378·0 | 76·0 | 243·0 | 104·5 | 95·0 | 818·0 |
| Hardness . . . | 5° | 5½° | 4° | 4° | 3° | 3° | — | 17° | 85° | 10½° | 5° | — |
| Free Ammonia . . | ·000 | ·080 | ·065 | ·060 | ·000 | ·084 | — | ·016 | ·002 | ·080 | ·080 | ·002 |
| Albuminoid Ammonia . | ·004 | ·001 | ·002 | ·002 | ·003 | ·010 | — | ·001 | ·016 | ·012 | ·004 | ·003 |
| Oxygen absorbed . . | ·045 | ·048 | ·160 | ·160 | ·040 | ·056 | — | ·035 | ·075 | ·124 | ·060 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS

| Source | 97<br>Chelmsford, Essex | 98<br>Ingatestone, Essex | 99<br>Maldon, Essex | 100<br>Coggeshall, Essex | 101<br>Braintree, Essex | 102<br>Bocking, Essex | 103<br>Colchester, Essex | 104<br>Earl's Colne, Essex | 105<br>S.Benfleet, Essex | 106<br>Pitsea, Essex | 107<br>Shoebury, Essex | 108<br>Upminster, Essex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate | 2·25 | 2·2 | 3·5 | 5·5 | 5·0 | 21·25 | 4·75 | 17·5 | 2·15 | 1·8 | 2·35 | 2·75 |
| Calcium Sulphate | — | — | — | — | — | — | — | — | — | — | — | — |
| Calcium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate | 1·75 | 1·05 | 1·55 | 5·5 | 5·5 | 4·4 | 5·55 | 10·4 | ·9 | — | 2·4 | 1·25 |
| Magnesium Sulphate | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate | 33·45 | 29·45 | 44·4 | 22·7 | 20·2 | 3·1 | 21·05 | 3·7 | 27·7 | 28·6 | 24·9 | 24·65 |
| Sodium Sulphate | 10·05 | 8·6 | 9·8 | 12·6 | 12·0 | 9·0 | 14·2 | 1·05 | 11·85 | 4·15 | 8·3 | 9·9 |
| Sodium Chloride | 61·7 | 38·4 | 70·0 | 75·4 | 69·2 | 28·05 | 102·25 | 5·9 | 45·2 | 38·45 | 54·1 | 29·5 |
| Sodium Nitrate | ·15 | ·25 | ·1 | ·4 | ·0 | ·15 | ·15 | ·15 | ·15 | ·1 | ·25 | ·1 |
| Silica, &c. | ·65 | ·05 | 1·15 | ($SiO_2$ 2·0)<br>2·9 | ·1 | 1·05 | ·05 | ·3 | ·6 | ·9 | 1·2 | ·35 |
| Total | 110·0 | 80·0 | 130·5 | 125·0 | 112·0 | 67·0 | 148·0 | 39·0 | 88·55 | 74·0 | 93·5 | 68·5 |
| Hardness | 4° | 4° | 6½° | 19° | 10° | 35° | 11° | 36° | 4° | 2½° | 5½° | 6° |
| Free Ammonia | ·075 | ·040 | ·085 | ·020 | ·112 | ·057 | ·104 | ·068 | ·025 | ·045 | ·032 | ·066 |
| Albuminoid Ammonia | ·001 | ·001 | ·002 | ·001 | ·006 | ·003 | ·004 | ·004 | ·002 | ·004 | ·001 | ·000 |
| Oxygen absorbed | ·032 | ·040 | ·075 | ·036 | ·038 | ·046 | ·008 | ·081 | ·042 | ·085 | ·016 | ·040 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS

|  | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Dagenham Dock, Essex | Rainham, Essex | Ilford, Essex | Ilford, Essex | Stratford, Essex | Walthamstow, Essex | Walthamstow, Essex | East Ham, Essex | East Ham, Essex | Barking, Essex | Leyton, Essex | Leyton, Essex |
| Calcium Carbonate | 10·25 | 25·5 | 10·0 | 7·5 | 12·7 | 20·8 | 8·7 | 11·7 | 25·5 | 8·75 | 12·7 | 14·0 |
| Calcium Sulphate | — | 23·9 | — | — | — | 8·2 | — | — | 16·6 | — | — | — |
| Calcium Chloride | — | 14·7 | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate | 6·90 | — | 4·1 | 5·4 | 5·9 | — | 5·9 | 6·2 | — | 5·9 | 6·2 | 4·8 |
| Magnesium Sulphate | — | — | — | — | — | 3·4 | — | — | 7·4 | — | 2·0 | — |
| Magnesium Chloride | — | 30·1 | — | — | — | — | — | — | 6·2 | — | — | — |
| Sodium Carbonate | 9·25 | — | 8·3 | 14·1 | 2·1 | — | 6·0 | 4·9 | — | 8·25 | — | 1·6 |
| Sodium Sulphate | 7·25 | — | 14·2 | 20·5 | 7·4 | — | 6·1 | 5·5 | — | 10·9 | 8·7 | 7·1 |
| Sodium Chloride | 9·4 | 120·7 | 4·9 | 12·8 | 6·1 | 4·3 | 4·0 | 5·0 | 65·0 | 13·0 | 5·4 | 4·4 |
| Sodium Nitrate | ·0 | — | ·35 | 1·5 | ·35 | 2·2 | 1·5 | ·7 | ·9 | ·75 | ·25 | ·25 |
| Silica, &c. | ·45 | 2·1 | ·15 | 1·2 | ·45 | ·1 | — | ·3 | 2·6 | ·45 | ·75 | ·85 |
| Total | 43·5 | 217·0 | 42·0 | 63·0 | 35·0 | 39·0 | 32·2 | 34·3 | 124·2 | 48·0 | 36·0 | 33·0 |
| Hardness | 23° | 140° | 16° | 14° | 24° | 32° | 16° | 20° | 54° | 18° | 25° | 25° |
| Free Ammonia | ·065 | ·14 | ·000 | ·094 | ·031 | ·001 | ·080 | ·055 | ·008 | ·064 | ·020 | ·052 |
| Albuminoid Ammonia | ·000 | ·003 | ·003 | ·001 | ·001 | ·004 | ·001 | ·002 | ·006 | ·001 | ·001 | ·003 |
| Oxygen absorbed | ·036 | ·060 | ·029 | ·006 | ·028 | ·100 | — | ·015 | ·040 | ·028 | ·030 | ·048 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS

| Sour | 121 Waltham Abbey, Essex | 122 Waltham Abbey, Essex | 123 Stansted, Essex | 124 Epping, Essex | 125 Dunmow, Essex | 126 Halstead, Essex | 127 Braintree, Essex | 128 Dedham, Essex | 129 Gt Bentley, Essex | 130 Brightlingsea, Essex | 131 Wyvenhoe, Essex | 132 Wyvenhoe, Essex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 2·5 | 15·2 | 26·0 | 9·35 | 26·0 | 25·25 | 5·0 | 17·75 | 6·0 | 8·75 | 7·2 | 5·25 |
| Calcium Sulphate . . | — | — | 3·0 | — | — | — | — | — | — | — | — | — |
| Calcium Chloride . . | — | — | 2·2 | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 1·9 | 8·6 | — | 4·55 | 4·1 | 2·35 | 5·5 | 9·65 | 2·4 | 6·9 | 5·9 | 5·75 |
| Magnesium Sulphate . | — | — | — | — | 5·4 | 2·9 | — | 1·6 | — | — | — | — |
| Magnesium Chloride . | — | — | 1·1 | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate . . | 27·85 | 1·8 | — | 16·7 | — | — | 20·2 | — | 19·8 | 15·15 | 18·2 | 19·05 |
| Sodium Sulphate . . | 17·5 | 15·3 | — | 31·95 | 5·0 | — | 12·0 | 8·2 | 2·8 | 5·2 | 14·2 | 16·0 |
| Sodium Chloride . . | 17·8 | 5·6 | ·15 | 12·2 | 8·9 | 14·2 | 69·2 | 44·05 | 4·0 | 25·9 | 70·9 | 117·0 |
| Sodium Nitrate . . | ·2 | ·15 | 5·0 | 1·65 | ·4 | ·35 | ·0 | ·0 | ·0 | ·6 | ·4 | ·4 |
| | | | Fe trace | | | | | | | | | |
| Silica, &c. . . . | 1·25 | ·35 | ·55 | ·6 | ·2 | ·95 | ·1 | ·35 | 1·0 | ·5 | ·2 | 2·55 |
| Total . . | 69·0 | 47·0 | 38·0 | 77·0 | 50·0 | 46·0 | 112·0 | 81·6 | 36·0 | 63·0 | 117·0 | 166·0 |
| Hardness . . . | 4½° | 26° | 30° | 20° | 35° | 30° | 17° | 32° | 9° | 17° | 15° | 9° |
| Free Ammonia . . | ·084 | ·050 | ·002 | ·000 | ·024 | ·016 | ·112 | ·056 | ·001 | ·000 | ·004 | ·100 |
| Albuminoid Ammonia . | ·004 | ·006 | ·011 | ·006 | ·002 | ·001 | ·005 | ·003 | ·005 | ·003 | ·001 | ·004 |
| Oxygen absorbed . . | ·100 | ·066 | — | ·064 | ·025 | ·012 | ·038 | ·028 | ·068 | ·029 | ·032 | ·036 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS OF ONE WATER COMPANY

| | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Billericay, Essex | Downham, Essex | Thundersley, Essex | Leigh, Essex | Southend, Essex | Southchurch, Essex | Gt. Wakering, Essex | Fobbing, Essex | Fobbing, Essex | Vange, Essex | Vange, Essex | Vange, Essex |
| Calcium Carbonate . | 1·75 | 2·4 | 2·0 | 1·75 | 1·85 | 1·25 | 1·75 | 33·3 | 3·75 | 3·75 | 2·4 | 2·0 |
| Calcium Sulphate . . | — | — | — | — | — | — | — | 1·7 | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | ·55 | ·85 | 1·05 | 1·05 | 1·2 | ·85 | 1·05 | — | ·9 | 1·35 | 1·75 | 1·2 |
| Magnesium Sulphate . | — | — | — | — | — | — | — | 26·1 | — | — | — | — |
| Magnesium Chloride . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate . . | 29·95 | 31·75 | 26·55 | 24·0 | 22·7 | 28·0 | 28·8 | — | 21·85 | 24·75 | 23·3 | 23·95 |
| Sodium Sulphate . . | 13·0 | 13·0 | 12·3 | 7·65 | 8·9 | 7·4 | 9·35 | 44·8 | 18·95 | 12·75 | 32·2 | 19·8 |
| Sodium Chloride . . | 32·4 | 44·2 | 46·3 | 48·85 | 54·7 | 50·65 | 57·75 | 25·9 | 27·4 | 43·5 | 23·1 | 25·7 |
| Sodium Nitrate . . | ·15 | ·25 | ·25 | ·2 | ·2 | ·3 | ·3 | ·1 | ·35 | ·8 | ·2 | ·2 |
| Silica, &c. . . . | 1·2 | ·55 | 1·55 | 1·5 | 1·45 | 1·55 | 1·5 | ·6 | 1·8 | 1·1 | ·55 | 1·15 |
| Total . . | 79·0 | 93·0 | 90·0 | 85·0 | 91·0 | 90·0 | 100·5 | 132·5 | 75·0 | 88·0 | 83·5 | 74·0 |
| Hardness . . . | 2·8° | 3½° | 4½° | 4½° | 5° | 4½° | 4½° | 70° | 5° | 7° | 6° | 4° |
| Free Ammonia . . | ·060 | ·053 | ·028 | ·052 | ·036 | ·024 | ·056 | ·130 | ·080 | ·024 | ·068 | ·056 |
| Albuminoid Ammonia . | ·002 | ·002 | ·002 | ·004 | ·003 | ·001 | ·007 | ·005 | ·040 | ·003 | ·004 | ·003 |
| Oxygen absorbed . . | ·044 | ·044 | ·040 | ·012 | ·016 | ·028 | ·088 | ·076 | ·111 | ·026 | ·076 | ·056 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK UNDER LOWER LONDON TERTIARIES. LONDON DEEP WELLS

|  | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Millwall, E. | Shaftesbury Avenue | Westminster, S.W. | King's Cross | City Road, E.C. | Bermondsey | Farringdon Street | Strand | Charing Cross | Clement's Inn | Caledonian Road | Lambeth |
| Calcium Carbonate . | 27·2 | 4·0 | 4·35 | 3·5 | 5·6 | 33·75 | 3·55 | 3·0 | 4·0 | 4·4 | 4·0 | 12·75 |
| Calcium Sulphate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 4·8 | 2·5 | 3·45 | ·35 | 2·25 | 6·40 | 1·95 | ·2·1 | 2·5 | 2·3 | 2·8 | 7·85 |
| Magnesium Sulphate . | 26·5 | — | — | — | — | 20·95 | — | — | — | — | — | — |
| Magnesium Chloride . | 2·7 | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Carbonate . . | — | 18·4 | 20·7 | 23·55 | 18·5 | — | 21·75 | 12·8 | 18·4 | 21·4 | 19·1 | 6·9 |
| Sodium Sulphate . . | — | 24·8 | 25·0 | 19·5 | 20·7 | 28·3 | 20·1 | 18·1 | 24·8 | 23·2 | 20·0 | 11·1 |
| Sodium Chloride . . | 295·2 | 30·3 | 28·3 | 15·1 | 15·2 | 31·35 | 18·8 | 18·2 | 30·3 | 23·6 | 16·7 | 14·4 |
| Sodium Nitrate . . | — | ·3 | ·3 | ·35 | ·5 | ·4 | ·3 | — | ·3 | ·2 | ·6 | — |
| Silica, &c. . . . | 3·6 | 1·3 | 2·4 | ·45 | ·35 | ·85 | 2·55 | 1·2 | 1·2 | ·4 | ·4 | 1·0 |
| Total . . | 360·0 | 81·6 | 84·5 | 62·8 | 63·1 | 122·0 | 69·0 | 55·4 | 81·5 | 75·5 | 63·6 | 54·0 |
| Hardness . . . . | 80° | 8° | 8° | 5½° | 8° | 60° | 7° | 6° | 7° | 8° | 7° | 20° |
| Free Ammonia . . | ·121 | ·082 | ·081 | ·061 | ·045 | ·050 | ·052 | ·072 | — | — | ·045 | — |
| Organic Ammonia . . | ·025 | ·001 | ·003 | ·003 | ·003 | ·008 | ·001 | ·002 | — | — | ·003 | — |
| Oxygen absorbed . . | ·304 | ·180 | — | ·007 | ·016 | ·084 | ·022 | ·000 | — | — | ·017 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK AT OR NEAR OUTCROP. ESSEX WELLS

| Source | 157<br>Little-bury, Essex | 158<br>Newport, Essex | 159<br>Saffron Walden, Essex | 160<br>Saffron Walden, Essex | 161<br>Linford, Essex | 162<br>Heydon, Essex | 163<br>Roydon, Essex | 164<br>Quendon, Essex | 165<br>Grays, Essex | 166<br>Grays, Essex | 167<br>Purfleet, Essex | 168<br>Aveley, Essex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 26·3 | 31·25 | 26·0 | 26·8 | 18·2 | 19·2 | 34·25 | 26·1 | 27·2 | 15·8 | 28·0 | 18·5 |
| Calcium Sulphate . . | 2·05 | 2·05 | 7·65 | 5·1 | 2·05 | 1·85 | — | 2·0 | 12·2 | 4·95 | 42·8 | 12·5 |
| Calcium Chloride . . | — | — | 5·65 | 4·7 | — | 2·35 | — | ·55 | 3·4 | ·7 | — | 6·7 |
| Calcium Nitrate . . | — | — | — | — | — | — | — | — | 4·6 | — | — | — |
| Magnesium Carbonate . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Sulphate . | — | 1·55 | — | — | 2·45 | — | 2·8 | — | — | — | 24·3 | — |
| Magnesium Chloride . | ·8 | 1·2 | ·4 | ·55 | ·6 | — | — | ·95 | 9·9 | 1·5 | 36·0 | 2·8 |
| Magnesium Nitrate . | — | — | 3·1 | 1·65 | — | 1·2 | — | — | — | — | — | 2·4 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Chloride . . | 2·0 | 1·0 | — | — | 4·05 | — | 3·8 | ·9 | 62·7 | 4·95 | 513·2 | — |
| Sodium Nitrate . . | 2·95 | ·3 | 9·7 | 5·35 | 1·7 | 4·1 | 1·2 | 2·45 | — | 5·6 | 2·3 | 9·6 |
|  |  | $Fe_2O_3$<br>1·3 |  |  |  |  | $FeCO_3$<br>1·2 |  |  |  |  |  |
| Silica, &c. . . . | 3·4 | 3·35 | ·8 | 1·35 | 1·95 | 1·3 | 1·15 | ·3 | 3·5 | 1·5 | 2·4 | ·5 |
| Total . . | 37·5 | 42·0 | 53·3 | 45·5 | 31·0 | 30·0 | 44·4 | 33·3 | 123·5 | 35·0 | 649·0 | 53·0 |
| Hardness . . . | 28° | 32° | 34° | 37° | 21½° | 23° | 31° | 24° | + 40° | 22° | + 150° | 34° |
| Free Ammonia . . | ·000 | ·000 | ·000 | ·001 | ·001 | ·000 | ·080 | ·000 | ·040 | ·000 | ·052 | ·000 |
| Organic Ammonia . . | ·002 | ·000 | ·006 | ·003 | ·004 | ·004 | ·005 | ·001 | ·002 | ·001 | ·004 | ·004 |
| Oxygen absorbed . . | ·024 | ·024 | ·015 | ·024 | ·012 | ·021 | ·120 | — | ·022 | ·025 | ·088 | ·036 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Chalk Wells. Herts.

| Source | 169<br>B. Stortford, Herts | 170<br>Watford, Herts | 171<br>Berkhampstead, Herts | 172<br>Ware, Hert | 173<br>Leavesden, Herts | 174<br>Eastbury, Herts | 175<br>Sawbridgeworth, Herts | 176<br>Barnet, Herts | 177<br>New Bushey, Herts | 178<br>New Bushey, Herts | 179<br>New Bushey, Herts | 180<br>New Bushey, Herts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 26·5 | 25·3 | 20·25 | 16·3 | 25·7 | 26·0 | 24·5 | 24·55 | 26·6 | 25·3 | 18·3 | 29·3 |
| Calcium Sulphate . . | 4·0 | 3·4 | ·45 | 5·65 | 1·15 | 3·75 | — | 4·05 | 10·55 | 5·25 | 9·2 | 14·1 |
| Calcium Chloride . . | — | — | — | — | 1·8 | — | — | — | — | — | — | — |
| Calcium Nitrate . . | — | 5·8 | 2·4 | — | — | — | — | — | 2·05 | 1·9 | — | ·8 |
| Magnesium Carbonate . | — | — | — | — | Mg2NO$_3$<br>·6 | — | 4·2 | — | — | — | — | — |
| Magnesium Sulphate . | — | — | — | 2·4 | — | — | — | ·2 | 2·0 | 1·15 | 3·35 | 2·5 |
| Magnesium Chloride . | 2·0 | 1·2 | — | — | ·35 | — | — | 2·4 | — | — | — | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | — | — | — | — | 2·30 | 6·65 | — | — | — | — | — |
| Sodium Chloride . . | ·5 | 2·3 | 2·15 | 4·3 | — | 3·3 | 4·6 | ·65 | 4·3 | 3·65 | 3·8 | 5·55 |
| Sodium Nitrate . . | 1·4 | — | — | 2·45 | 4·7 | 2·5 | ·4<br>Fe trace | 3·5 | 1·85 | 1·9 | 2·6 | 5·2 |
| Silica, &c. . . . | 2·6 | 1·5 | 1·25 | 2·2 | 2·4 | ·15 | 3·75 | 1·85 | 1·4 | 1·35 | 1·25 | ·65 |
| Total . . | 37·0 | 39·5 | 26·5 | 33·3 | 36·7 | 38·0 | 44·1 | 37·2 | 48·75 | 40·5 | 38·5 | 58·1 |
| Hardness . . . | 28° | 30° | 22° | 19° | 30° | 26° | 30° | 27° | 32° | 30° | 26° | 38° |
| Free Ammonia . . | ·002 | ·001 | ·000 | ·056 | ·000 | ·003 | ·015 | ·001 | ·131 | ·005 | ·014 | — |
| Albuminoid Ammonia . | ·003 | ·006 | ·006 | ·014 | ·000 | ·002 | ·001 | ·008 | ·013 | ·006 | ·013 | — |
| Oxygen absorbed . . | — | ·027 | ·037 | ·213 | ·000 | ·024 | ·011 | ·069 | ·146 | ·054 | ·135 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK WATERS. SUFFOLK

| Source | 181<br>Brantham | 182<br>Thorndon | 183<br>Eye | 184<br>Brandon | 185<br>Stoke-by-Clare | 186<br>Stoke-by-Clare | 187<br>Shotley | 188<br>Wood-bridge | 189<br>Wolver-stone | 190<br>Felixstowe | 191<br>Stow-market | 192<br>Hales-worth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 23·5 | 29·3 | 32·0 | 18·7 | 28·2 | 28·5 | 25·3 | 29·7 | 22·5 | 21·25 | 31·7 | 28·3 |
| Calcium Sulphate . . | — | 4·8 | 8·85 | 8·5 | 13·1 | 10·9 | 35·4 | 23·45 | — | — | 6·95 | 19·0 |
| Calcium Chloride . . | — | — | — | Ca2NO$_3$<br>6·95 | — | — | 12·2 | 5·4 | — | — | — | — |
| Magnesium Carbonate . | 6·45 | — | — | — | — | — | — | — | 5·45 | 5·35 | — | — |
| Magnesium Sulphate . | 7·2 | — | ·55 | — | 7·8 | ·65 | — | — | 13·0 | 7·0 | ·5 | 5·1 |
| Magnesium Chloride . | 1·75 | 3·95 | 1·2 | 2·0 | 2·5 | 1·35 | 65·2 | 6·7 | ·55 | 5·1 | — | ·4 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | — | — | — | — | — | — | — | — | — | 3·25 | — |
| Sodium Chloride . . | 22·9 | 1·2 | 4·45 | 3·5 | — | 1·65 | 390·2 | 4·55 | 44·9 | 28·15 | 6·6 | 9·4 |
| Sodium Nitrate . . | ·15 | ·3 | ·7 | — | 2·7 | ·95 | ·5 | 15·5 | ·6 | ·6 | — | ·35 |
| Silica, &c. . . . | 2·85 | 1·45 | 2·75 | 3·25 | 1·0 | 1·5 | 1·2 | 1·8 | — | 2·95 | 1·0 | ·45 |
| Total . . | 64·8 | 41·0 | 50·5 | 42·9 | 55·3 | 45·5 | 530·0 | 87·1 | 87·0 | 70·4 | 50·0 | 63·0 |
| Hardness . . . | 40° | 32° | 34½° | 31° | 34° | 36° | 100° | 58° | 48° | 34° | 30° | 50° |
| Free Ammonia . . | — | ·020 | ·007 | ·002 | ·003 | ·000 | ·164 | ·000 | ·092 | ·001 | ·000 | ·012 |
| Albuminoid Ammonia . | — | ·003 | ·004 | ·000 | ·001 | ·004 | ·001 | ·004 | ·006 | ·004 | ·000 | ·006 |
| Oxygen absorbed . . | — | ·088 | ·130 | ·018 | ·033 | ·047 | ·039 | ·013 | ·036 | ·025 | ·018 | ·160 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK WELLS. NORFOLK, CAMBS., MIDDLESEX, AND RUTLAND

| Source | 193<br>Wymondham, Norfolk | 194<br>Cromer, Norfolk | 195<br>Norwich, Norfolk | 196<br>Ely, Cambs. | 197<br>Pampisford, Cambs. | 198<br>Linton | 199<br>Cherryhinton, Cambs. | 200<br>Fulbourn Cambs. | 201<br>Fulbourn Cambs. | 202<br>Fulbourn Cambs. | 203<br>Pinner, Middlesex | 204<br>Ashwell, Rutland |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 25·65 | 19·3 | 14·3 | 18·7 | 25·8 | 27·7 | 20·35 | 19·85 | 19·35 | 21·25 | 27·8 | 21·7 |
| Calcium Sulphate . . | ·85 | 2·55 | 4·25 | 2·1 | 2·55 | 1·8 | 2·55 | 2·55 | 2·05 | 4·65 | — | 1·85 |
| Calcium Chloride . . | — | — | — | 2·6 | — | — | — | — | — | 2·75 | — | 2·65 |
| Calcium Nitrate . . | — | — | 5·8 | 2·8 | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | — | — | — | — | — | — | — | — | — | — | 2·9 | $\text{Mg2NO}_3$<br>1·05 |
| Magnesium Sulphate . | 1·5 | 1·75 | — | — | 2·5 | 2·5 | ·9 | ·8 | 1·0 | — | 4·8 | — |
| Magnesium Chloride . | — | — | 1·0 | ·6 | — | — | 1·75 | 1·6 | 1·2 | 1·35 | — | ·65 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | 1·35 | ·75 | — | — | — | — | — | — | — | — | 4·55 | — |
| Sodium Chloride . . | 4·45 | 6·6 | 3·4 | — | 3·1 | 3·1 | ·55 | ·8 | 1·15 | — | 8·25 | — |
| Sodium Nitrate . . | ·4 | ·15 | — | — | 2·6 | 2·0 | 3·95 | 3·95 | 4·05 | 7·1 | ·3 | 3·65 |
| Silica, &c. . . . | 2·8 | 1·4 | 2·25 | 3·2 | 2·05 | 1·5 | 2·45 | 1·95 | 2·2 | 1·9 | 2·6 | 1·45 |
| Total . . | 37·0 | 32·5 | 31·0 | 30·0 | 38·6 | 38·6 | 32·5 | 31·5 | 31·0 | 39·0 | 51·2 | 33·0 |
| Hardness . . . | 28½° | 19° | 21½° | 21° | 30° | 30° | 24° | 24° | 23° | 29° | 32° | 24° |
| Free Ammonia . . | ·002 | ·002 | ·000 | ·000 | ·000 | ·000 | ·006 | ·001 | ·002 | ·001 | ·004 | ·001 |
| Albuminoid Ammonia . | ·005 | ·000 | ·002 | ·005 | ·000 | ·000 | ·007 | ·004 | ·005 | ·003 | ·003 | ·002 |
| Oxygen absorbed . . | ·124 | ·016 | ·018 | ·032 | ·015 | ·016 | — | — | — | — | ·012 | ·024 |

### RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

Chalk Wells. Surrey 205–209. Sussex 210–214. Bucks 215, 216

| | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Sutton | Nr. Guildford | Guildford | Guildford | Guildford | Nr. Eastbourne | Nr. Eastbourne | Warmock | Brighton | Brighton | Slough | Little Kimble |
| Calcium Carbonate . . | 23·7 | 12·25 | 20·85 | 20·0 | 22·0 | 18·8 | 15·75 | 18·05 | 16·0 | 14·5 | 16·25 | 23·2 |
| Calcium Sulphate . . | 3·1 | — | 1·55 | 1·0 | ·35 | ·55 | 1·9 | 1·4 | 2·4 | 3·2 | — | — |
| Calcium Chloride . . | — | — | 1·6 | 2·1 | — | ·9 | 2·65 | 1·95 | ·55 | ·55 | — | — |
| Calcium Nitrate . . | 8·2 | — | — | — | — | 2·4 | 1·85 | 1·55 | 2·15 | 4·45 | — | — |
| Magnesium Carbonate . | — | 7·35 | — | — | — | — | — | — | — | — | 3·6 | 2·0 |
| Magnesium Sulphate . | — | — | — | — | ·75 | — | — | — | — | — | — | 3·5 |
| Magnesium Chloride . | 1·8 | — | 1·25 | ·4 | 1·0 | 1·2 | 1·0 | 1·0 | ·6 | 1·0 | — | — |
| Sodium Carbonate . . | — | 2·3 | — | — | — | — | — | — | — | — | 3·7 | — |
| Sodium Sulphate . . | — | 4·7 | — | — | — | — | — | — | — | — | 7·55 | — |
| Sodium Chloride . . | 2·25 | 4·45 | — | ·5 | 1·8 | 3·85 | 4·05 | 1·5 | 2·0 | 3·6 | 5·6 | 2·3 |
| Sodium Nitrate . . | 2·9 | ·15 | 3·2 | 3·75 | 2·5 | — | — | — | — | — | 1·25 | ·2 |
| Silica, &c. . . . | 2·55 | — | ·85 | ·65 | ·8 | 1·3 | 1·8 | 1·05 | 1·3 | 1·2 | 1·45 | 1·9 |
| Total . . | 44·5 | 31·2 | 29·3 | 28·4 | 29·2 | 29·0 | 29·0 | 26·5 | 25·0 | 28·5 | 39·4 | 33·1 |
| Hardness . . . | 34° | 21° | 24° | 23° | 24° | 21° | 19° | 20° | 19° | 24° | 22° | 24° |
| Free Ammonia . . | ·000 | ·001 | ·002 | ·001 | ·002 | ·001 | ·000 | ·000 | ·000 | ·000 | ·023 | ·014 |
| Albuminoid Ammonia . | ·003 | ·003 | ·004 | ·003 | ·035 | ·002 | ·001 | ·001 | ·001 | ·006 | ·005 | ·002 |
| Oxygen asborbed . . | ·066 | ·022 | ·021 | ·016 | ·021 | ·025 | ·015 | ·023 | ·006 | ·055 | ·023 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

CHALK. DORSET 217–220. ISLE OF WIGHT 221–224. WILTS 225–228

| Source | 217 Swanage | 218 Corfe Mullen | 219 Nr. Bournemouth | 220 Wimborne | 221 Nr. Totland Bay | 222 Shalcombe, I. of W. | 223 Nr. Freshwater, I. of W. | 224 Totland Bay, I. of W. | 225 Warminster | 226 Shrewton | 227 Marlborough | 228 Nr. Swindon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate | 18·3 | 21·25 | 18·5 | 23·25 | 20·0 | 17·9 | 16·8 | 20·0 | 19·0 | 19·0 | 21·2 | 31·75 |
| Calcium Sulphate | — | 2·55 | 1·0 | — | 5·1 | 1·3 | 4·1 | 5·1 | 1·1 | ·4 | ·35 | 2·55 |
| Calcium Chloride | — | — | — | — | — | — | — | — | 1·6 | ·95 | — | 1·4 |
| Calcium Nitrate | — | — | — | — | — | — | — | — | 2·9 | 1·7 | 2·35 | — |
| Magnesium Carbonate | — | — | — | 1·9 | — | — | — | — | — | — | — | — |
| Magnesium Sulphate | ·5 | ·85 | 1·7 | 3·5 | 2·5 | — | 1·9 | 2·5 | — | — | — | Mg2NO$_3$<br>1·8 |
| Magnesium Chloride | — | 1·6 | — | — | — | — | 6·25 | — | — | — | ·4 | ·6 |
| Sodium Carbonate | ·35 | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Chloride | 5·65 | 3·0 | 3·8 | 4·0 | 15·2 | 6·3 | 26·95 | 15·2 | — | 1·15 | 1·2 | — |
| Sodium Nitrate | 1·5 | ·6 | 1·4 | ·2 | ·9 | 2·0 | 1·4 | ·9 | — | — | — | — |
| Silica, &c. | 1·5 | ·65 | ·6 | 1·15 | ·9 | — | — | ·9 | 1·9 | 1·3 | 1·5 | 1·4 |
| Total | 27·8 | 30·5 | 27·0 | 34·0 | 44·6 | 27·5 | 57·4 | 44·6 | 26·5 | 24·5 | 27·0 | 39·5 |
| Hardness | 18° | 26·5° | 19° | 25° | 25° | 19° | 28° | 25° | 27° | 19° | 23° | 33½° |
| Free Ammonia | ·003 | ·000 | ·000 | ·005 | ·003 | — | — | ·003 | ·002 | ·008 | ·000 | ·000 |
| Albuminoid Ammonia | ·011 | ·001 | ·003 | ·001 | ·005 | — | — | ·005 | ·002 | ·005 | ·001 | ·003 |
| Oxygen absorbed | ·074 | ·008 | ·004 | ·022 | ·025 | — | — | ·025 | ·075 | ·018 | ·014 | ·016 |

# RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

## CHALK WELLS. HAMPSHIRE

| Source | 229<br>Foxbury | 230<br>Forton | 231<br>Foxbury | 232<br>Bury Cross | 233<br>Fissure A, Foxbury | 234<br>Fissure B, Foxbury | 235<br>Clapperton | 236<br>Nr. Portsmouth | 237<br>Portsmouth | 238<br>Otterbourne | 239<br>Owlesbury | 240<br>Andover |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 17·15 | 5·2 | 19·5 | 13·5 | 15·5 | 25·0 | 17·75 | 20·8 | 18·75 | 22·0 | 18·3 | 21·35 |
| Calcium Sulphate . . | — | 19·7 | — | — | — | 6·45 | 1·65 | ·7 | — | ·7 | ·55 | 1·15 |
| Calcium Chloride . . | — | — | — | — | — | — | — | ·85 | — | 1·4 | — | — |
| Calcium Nitrate . . | — | — |  | — | — | — | 3·0 | 2·55 | — | 2·55 | 2·9 | 4·9 |
| Magnesium Carbonate . | 5·3 | — | 4·35 | 5·8 | 8·75 | — | — | — | 1·0 | — | — | — |
| Magnesium Sulphate . | 1·0 | 13·0 | 9·5 | — | — | 9·55 | — | — | 16·0 | — | — | — |
| Magnesium Chloride . | — | 2·75 | 2·15 | — | — | 9·1 | 1·0 | ·8 | — | ·6 | — | ·4 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | ·5 | — |
| Sodium Sulphate . . | 9·3 | — | — | 11·1 | 8·3 | — | — | — | 5·05 | — | — | — |
| Sodium Chloride . . | 59·05 | 69·35 | 67·3 | 11·7 | 37·1 | 127·0 | 1·4 | ·75 | 81·35 | ·25 | ·4 | 2·15 |
|  |  | $Mg2NO_3$ |  |  |  |  |  |  |  |  |  |  |
| Sodium Nitrate . . | ·15 | ·65 | ·4 | ·8 | ·8 | ·4 | — | — | ·25 | — | — | — |
| Silica, &c. . . . | ·55 | 2·35 | 1·6 | ·6 | ·35 | ·5 | 2·7 | 1·05 | 3·2 | 3·0 | 3·35 | 2·05 |
| Total . . | 92·5 | 113·0 | 104·8 | 43·5 | 70·8 | 178·0 | 27·5 | 27·5 | 125·6 | 30·5 | 26·0 | 32·0 |
| Hardness . . . | 20° | 33° | 37° | 16° | 24° | 40° | 23° | 20° | 24° | 22° | 19° | 22½° |
| Free Ammonia . . | ·070 | ·000 | ·066 | ·118 | — | — | ·000 | ·000 | ·088 | ·000 | ·000 | ·000 |
| Albuminoid Ammonia . | ·003 | ·000 | ·001 | ·005 | — | — | ·003 | ·001 | ·000 | ·003 | ·001 | ·003 |
| Oxygen absorbed . . | ·042 | ·003 | ·017 | ·021 | — | — | ·126 | ·063 | ·096 | ·008 | ·029 | ·022 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK. HAMPSHIRE, 241–244. KENT, 245–262

| Source | 241<br>Winchester | 242<br>Soberton | 243<br>Woolston | 244<br>Aldershot | 245<br>Dover, Kent | 246<br>Dover, Kent | 247<br>Rochester | 248<br>Chatham | 249<br>Ramsgate | 250<br>Boxley | 251<br>Orpington | 252<br>Gravesend |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 19·5 | 25·0 | 21·9 | 23·6 | 20·5 | 19·0 | 25·0 | 25·3 | 24·7 | 20·85 | 23·7 | 25·0 |
| Calcium Sulphate . . | ·9 | — | 6·2 | 3·6 | 1·15 | 1·85 | 2·4 | — | 4·7 | ·9 | 2·0 | 2·55 |
| Calcium Chloride . . | — | — | 4·15 | — | 1·4 | ·7 | — | — | 1·8 | — | ·8 | — |
| Calcium Nitrate . . | 5·9 | — | — | — | 2·65 | 4·9 | — | — | 5·55 | — | 11·2 | — |
| Magnesium Carbonate . | — | 1·3 | — | — | — | — | — | 1·1 | — | — | — | — |
| Magnesium Sulphate . | — | 1·0 | — | ·95 | — | — | 1·9 | — | — | — | — | — |
| Magnesium Chloride . | 1·2 | — | 11·5 | — | ·8 | 1·2 | — | — | 4·95 | 1·2 | 2·0 | 1·35 |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate . . | — | ·7 | — | — | — | — | — | ·8 | — | — | — | — |
| Sodium Chloride . . | 1·3 | 3·1 | 105·3 | 3·6 | 1·5 | 5·8 | 6·3 | 3·8 | 20·7 | 2·05 | 8·4 | 2·55 |
| Sodium Nitrate . . | — | — | ·5 | 2·15 | — | — | 3·0 | 2·1 | — | 7·2 | — | 5·05 |
| | | | Fe present | | | | | | | | | |
| Silica, &c. . . . | ·7 | 1·5 | 8·45 | 3·1 | 2·5 | 2·05 | 1·9 | 1·3 | 1·1 | 1·8 | 1·4 | 1·50 |
| Total . . | 29·5 | 32·6 | 158·0 | 37·0 | 30·5 | 35·5 | 40·5 | 34·4 | 63·5 | 34·0 | 49·5 | 38·0 |
| Hardness . . . | 20° | 24½° | 50° | 26° | 26° | 22° | 24° | 24° | 28° | 21½° | 26° | 25° |
| Free Ammonia . . | ·001 | ·001 | ·160 | ·001 | ·000 | ·000 | ·000 | ·001 | ·000 | ·000 | ·005 | ·000 |
| Albuminoid Ammonia . | ·002 | ·001 | ·011 | ·001 | ·001 | ·001 | ·002 | ·001 | ·002 | ·001 | ·006 | ·006 |
| Oxygen absorbed . . | ·014 | ·011 | ·040 | ·006 | ·032 | ·029 | ·015 | ·024 | ·078 | ·021 | ·030 | ·042 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### CHALK. KENT 253–262

| Source | 253<br>Swanscombe | 254<br>Greenhithe | 255<br>Gravesend | 256<br>Gravesend | 257<br>St. Mary Cray | 258<br>Halling | 259<br>Northfleet | 260<br>Faversham | 261<br>Deptford | 262<br>Nr. Herne Bay | 263<br>Watlington, Oxford | 264<br>Mablethorpe, Lincs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 27·5 | 25·0 | 25·0 | 29·7 | 22·5 | 15·0 | 27·25 | 26·2 | 27·3 | 3·35 | 28·7 | 29·3 |
| Calcium Sulphate . . | 4·75 | — | 2·55 | 3·55 | 1·15 | — | — | ·7 | 19·15 | — | ·55 | — |
| Calcium Chloride . . | 4·55 | — | 3·45 | 4·55 | ·8 | — | — | 2·2 | 1·25 | — | 3·75 | — |
| | | | | | | | | | | | Ca2 NO$_3$ | |
| Magnesium Carbonate . | — | ·85 | — | 2·55 | — | ·85 | 2·45 | — | — | 3·5 | 1·15 | — |
| | | | | | | | | | | | Mg2 NO$_3$ | |
| Magnesium Sulphate . | — | — | — | — | — | 1·0 | 1·0 | — | — | — | ·6 | 7·3 |
| Magnesium Chloride . | 2·75 | — | ·55 | — | ·8 | — | — | 1·1 | 12·9 | — | — | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | 23·0 | — | 6·2 |
| Sodium Sulphate . . | — | 1·9 | — | — | — | — | — | — | — | 41·75 | — | — |
| Sodium Chloride . . | — | 10·9 | — | 9·9 | ·5 | — | 4·1 | — | 22·1 | 36·3 | ·9 | 48·1 |
| Sodium Nitrate . . | 9·55 | 2·0 | 4·75 | 5·5 | 3·0 | 3·3 | ·75 | 1·8 | — | — | — | — |
| | KNO$_3$ | | Mg2 NO$_3$ | | | | | | | KCl 5·65 | | |
| | 1·55 | | 2·75 | | | | | | | | | |
| Silica, &c. . . . | 2·85 | ·35 | ·95 | 1·05 | ·25 | 1·55 | 1·95 | 1·0 | 4·3 | ·45 | 2·35 | 1·1 |
| Total . . | 53·5 | 41·0 | 40·0 | 56·8 | 29·0 | 21·7 | 37·5 | 33·0 | 87·0 | 114·0 | 38·0 | 92·0 |
| Hardness . . . | 30° | 25° | 24° | 36° | 26° | 15° | 27° | — | 40° | 5° | 32° | 31° |
| Free Ammonia . . | ·002 | ·006 | ·006 | ·000 | ·001 | ·000 | — | — | ·050 | ·072 | ·022 | ·200 |
| Albuminoid Ammonia . | ·022 | ·014 | ·003 | ·001 | ·002 | ·001 | — | — | ·005 | ·004 | ·010 | ·016 |
| Oxygen absorbed . . | ·114 | ·068 | ·018 | ·009 | ·020 | ·021 | — | — | — | ·105 | ·057 | ·072 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Chalk Waters

| | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Aldermaston, Berks | Reading, Berks | Windsor, Berks | Luton, Beds | Luton, Beds | Markyate, Beds | Hornsea, Yorks | Hornsea, Yorks | Hollyn, Yorks | Manton, Wilts | Gentofle, Denmark | I. of Funen, Denmark |
| Calcium Carbonate . . | 21·75 | 26·35 | 21·8 | 20·3 | 23·7 | 25·8 | 19·25 | 23·25 | 26·65 | 27·0 | 19·25 | 13·5 |
| Calcium Sulphate . . | — | ·85 | 6·35 | 1·85 | 7·1 | ·35 | 6·25 | — | 18·2 | 4·55 | — | — |
| Calcium Chloride . . | — | ·8 | — | ·95 | — | 2·0 | — | — | — | 3·05 | — | — |
| Calcium Nitrate . . | — | 3·5 | — | 4·1 | 12·9 | 1·6 | — | — | — | Mg 1·4 | — | — |
| Magnesium Carbonate . | 3·7 | — | — | — | — | — | — | 1·35 | — | — | 2·95 | 1·05 |
| Magnesium Sulphate . | — | — | — | — | — | — | 3·6 | 6·8 | 31·6 | — | — | — |
| Magnesium Chloride . | — | ·8 | 2·35 | — | 1·35 | — | 1·6 | — | — | ·6 | — | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | — | 19·0 |
| Sodium Sulphate . . | 2·4 | — | — | — | — | — | — | ·5 | 38·85 | — | 2·95 | ·25 |
| Sodium Chloride . . | 2·8 | ·65 | 1·05 | 1·15 | 4·8 | — | 45·85 | 9·25 | 43·55 | — | 3·05 | 5·05 |
| Sodium Nitrate . . | ·2 | — | 3·5 | — | — | — | — | ·15 | — | 4·0 | — | — |
| | | | | | | | Fe trace | | (Fe ·3) | | | FeCO$_3$ ·5 |
| Silica, &c. . . . | 1·65 | 1·55 | 1·45 | 1·65 | 2·15 | ·25 | 1·45 | ·2 | 4·15 | 1·0 | ·6 | ·65 |
| Total . . | 32·5 | 34·5 | 36·5 | 30·0 | 52·0 | 30·0 | 78·0 | 41·5 | 163·0 | 41·6 | 28·8 | 40·0 |
| Hardness . . . | 19° | 24° | 30½° | 25° | 28½° | 32° | — | — | 62½° | — | — | — |
| Free Ammonia . . | ·010 | ·001 | ·000 | ·000 | ·000 | ·000 | ·116 | ·076 | ·096 | ·000 | ·000 | — |
| Albuminoid Ammonia . | ·005 | ·001 | ·004 | ·001 | ·000 | ·0015 | ·008 | ·070 | ·008 | ·001 | ·000 | — |
| Oxygen absorbed . . | ·070 | ·006 | ·023 | ·007 | ·007 | ·004 | — | — | ·096 | ·030 | ·014 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### GREENSAND WATERS. UPPER GREENSAND, 277–280. LOWER GREENSAND, 281–288

| Source | 277<br>Welton-le-Marsh, Lincs. | 278<br>Plumpton, Sussex | 279<br>East Harting, Sussex | 280<br>Little Kimble, Bucks | 281<br>Shere, Surrey | 282<br>Ottershaw Park, Surrey | 283<br>Rogate, Sussex | 284<br>Petersfield, Hamps | 285<br>Wanboro, Wilts. | 286<br>Linslade, Beds | 287<br>Leighton Buzzard, Beds | 288<br>Cheddington, Bucks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . . | 2·6 | 26·5 | 28·2 | 23·2 | 9·0 | 12·0 | ·85 | 14·0 | 21·0 | 26·3 | 6·75 | 18·65 |
| Calcium Sulphate . . | — | — | — | — | 1·65 | 8·15 | 2·2 | — | 2·4 | 10·9 | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | 2·65 | — | — | — |
| Magnesium Carbonate . | ·7 | 1·25 | 2·0 | 2·0 | — | — | — | 2·4 | — | — | 2·0 | 1·6 |
| Magnesium Sulphate . | — | 1·5 | — | 3·5 | — | 2·4 | — | — | — | 3·75 | — | — |
| Magnesium Chloride . | — | — | — | — | 1·0 | 1·0 | — | — | ·7 | 1·5 | — | — |
| Sodium Carbonate . . | 27·6 | — | ·35 | — | — | — | — | — | — | — | — | 3·25 |
| |  | $K_2SO_4$<br>1·9 |  |  |  |  |  |  |  |  |  |  |
| Sodium Sulphate . . | 4·0 | 1·1 | 2·35 | — | — | — | — | 4·45 | — | — | 1·75 | 2·65 |
| Sodium Chloride . . | 3·95 | 4·45 | 3·95 | 2·3 | ·75 | 58·85 | 2·5 | 2·65 | — | — | 2·65 | 4·3 |
| Sodium Nitrate . . | — | ·3 | 1·1 | ·2 | 1·25 | ·25 | 1·0 | 0·15 | 8·05 | ·4 | 2·05 | ·2 |
| Ferrous Carbonate . . | — | 1·2 | — | — | — | ·25 | trace | ·4 | — | trace | trace | — |
| Silica, &c. . . . | ·65 | ·2 | 1·05 | 1·9 | 1·55 | 1·9 | ·85 | ·35 | — | 1·45 | ·3 | ·85 |
| Total . . | 39·5 | 38·4 | 39·0 | 33·1 | 15·2 | 84·8 | 7·4 | 24·4 | 34·8 | 44·3 | 15·5 | 31·5 |
| Hardness . . . | 4° | — | 26° | 24° | 11° | 22° | 2½° | 17° | — | 35° | 9° | 21° |
| Free Ammonia . . | ·060 | — | ·016 | ·014 | — | ·018 | ·000 | ·000 | — | ·006 | ·002 | ·048 |
| Albuminoid Ammonia . | ·002 | — | ·006 | ·002 | — | ·001 | ·000 | ·001 | — | ·007 | ·003 | ·001 |
| Oxygen absorbed . . | ·020 | — | ·047 | — | — | ·033 | ·016 | ·010 | — | ·050 | ·026 | ·009 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Lower Greensand, 289–295. Hastings Bed, 296–300

| Source | 289<br>Wing, Bucks | 290<br>Saltwood Kent | 291<br>Seven-oaks, Kent | 292<br>Dunton Green, Kent | 293<br>Kemsing, Kent | 294<br>Halling, Kent | 295<br>Reigate, Surrey | 296<br>Southboro, Kent | 297<br>Stye Place, Kent | 298<br>Tunbridge Wells, Kent | 299<br>Cran-brook, Kent | 300<br>Horsted Keynes, Sussex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 38·15 | 7·5 | 16·8 | 18·2 | 14·1 | 15·0 | 7·5 | 5·0 | ·4 | 2·25 | 7·25 | 22·15 |
| Calcium Sulphate . . | 4·6 | 5·25 | 2·7 | 2·8 | 2·95 | — | 4·4 | — | — | — | 1·35 | — |
| Calcium Chloride . . | — | 1·1 | 1·95 | ·4 | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | — | — | — | — | — | ·85 | — | 2·1 | ·15 | 1·05 | — | — |
| Magnesium Sulphate . | 14·85 | — | — | — | ·2 | 1·0 | — | — | — | — | 3·8 | 5·05 |
| Magnesium Chloride . | — | 1·2 | ·8 | 1·75 | — | — | 1·95 | — | — | — | ·75 | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | 2·2 | 65·2 | 11·95 | — | — |
| Sodium Sulphate . . | 6·35 | — | — | — | — | — | — | 2·9 | — | 5·2 | — | — |
| Sodium Chloride . . | 7·6 | 1·75 | ·7 | ·4 | 3·65 | 3·3 | ·9 | 5·6 | 24·9 | 4·95 | 4·7 | 4·35 |
| Sodium Nitrate . . | ·15 | 6·4 | 2·3 | ·3 | ·05 | ·35 | 5·6 | 2·05 | ·3 | — | ·2 | ·5 |
| Ferrous Carbonate . | — | — | — | — | — | — | — | — | — | ·3 | trace | ·5 |
| Silica, &c. . . . | ·3 | 1·9 | ·25 | 1·45 | ·85 | 1·2 | ·15 | 1·65 | 2·05 | ·6 | 1·45 | 2·45 |
| Total . . | 72·0 | 25·1 | 25·5 | 25·3 | 21·8 | 21·7 | 20·5 | 21·5 | 93·0 | 26·3 | 19·5 | 35·0 |
| Hardness . . . | 55° | 10½° | 17½° | 20° | 17° | 15° | 13° | 8½° | ·5 | 3° | 11° | 24° |
| Free Ammonia . . | ·002 | ·032 | ·000 | ·000 | ·002 | ·000 | ·000 | ·002 | ·000 | ·048 | ·002 | ·002 |
| Albuminoid Ammonia . | ·016 | ·007 | ·002 | ·000 | ·002 | ·001 | ·002 | ·003 | ·000 | ·004 | ·002 | ·005 |
| Oxygen absorbed . . | ·448 | ·080 | ·010 | ·008 | — | ·021 | ·008 | ·009 | ·048 | ·028 | ·007 | ·044 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

Purbeck Beds, 301. Upper and Middle Oolite, 302–307. Lower Oolite, 308–312

| | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Swanage, Dorset | Nr. Swindon, Wilts | Renhold, Beds | Callow, Berks | Callow, Berks | Irton, Yorks | Woodhall, Lincs | Bath, Somerset | Turweston Bucks | Buckminster, Leicester | Buckminster, Leicester | Harston, Leicester |
| Calcium Carbonate | 22·0 | 31·3 | 26·5 | ·25 | 6·25 | 12·9 | 20·5 | 21·2 | 25·5 | 10·0 | 11·9 | 22·75 |
| Calcium Sulphate | 23·8 | — | — | — | — | 2·2 | 4·1 | 11·9 | — | 8·2 | — | 10·55 |
| Calcium Chloride | — | — | — | — | — | — | 215·2 | — | — | — | — | — |
| Magnesium Carbonate | — | 3·45 | 5·05 | ·15 | 2·6 | — | — | — | 1·9 | — | — | — |
| Magnesium Sulphate | 6·4 | — | 16·8 | — | — | 1·45 | — | ·5 | — | 2·4 | — | 1·5 |
| Magnesium Chloride | — | — | — | — | — | — | 144·2 | — | — | — | — | — |
| Sodium Carbonate | — | 14·05 | — | 73·9 | 41·4 | — | — | ·6 | 5·85 | — | ·65 | — |
| Sodium Sulphate | ·3 | 48·3 | 89·6 | — | 8·6 | ·45 | — | — | 8·95 | 1·6 | 1·8 | 2·05 |
| Sodium Chloride | 9·3 | 11·15 | 27·55 | 68·8 | 46·95 | 3·95 | 1741·5 | 2·7 | 4·6 | 5·4 | 1·8 | 9·25 |
| Sodium Nitrate | 3·4 | ·2 | ·35 | ·4 | ·35 | ·45 | ·5 | 2·9 | ·05 | 2·7 | ·15 | 3·0 |
| | | $K_2SO_4$ | $K_2SO_4$ | KCl | KCl | Fe trace | NaBr | | | | | $K_2SO_4$ |
| | | 14·4 | 7·8 | 8·4 | 5·55 | | 6·2 | | | | | 5·1 |
| Silica, &c. | ·8 | 4·45 | ·15 | 2·1 | 2·8 | ·6 | — | 1·2 | 1·05 | ·7 | ·2 | 2·8 |
| Total | 66·0 | 127·3 | 173·8 | 154·0 | 114·5 | 22·0 | about 2200 | 41·0 | 47·9 | 31·0 | 16·5 | 57·0 |
| Hardness | 40° | 28° | 40° | 6° | 9° | 16° | — | 28½° | 26° | 16° | 11½° | 28° |
| Free Ammonia | ·004 | ·091 | ·001 | ·082 | ·087 | ·000 | — | ·000 | ·004 | ·002 | ·006 | ·000 |
| Albuminoid Ammonia | ·005 | ·006 | ·004 | ·007 | ·006 | ·002 | — | ·014 | ·003 | ·004 | ·002 | ·001 |
| Oxygen absorbed | ·044 | ·040 | ·018 | ·200 | ·116 | ·030 | — | ·034 | — | ·052 | ·064 | ·019 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Lincolnshire Limestone. Lower Oolite

| | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 | 323 | 324 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Eltow | Crowland | Market Deeping | Thurlby | Thurlby | St. James Deeping | Caythorpe | Caythorpe | Bourne | Stoke Park | Stroxton | Peterboro |
| Calcium Carbonate . | 20·25 | 5·5 | 8·65 | 23·7 | 24·0 | 8·15 | 34·75 | 20·0 | 22·8 | 18·7 | 22·0 | 2·75 |
| Calcium Sulphate . . | — | — | — | 3·4 | 6·45 | — | — | 16·3 | 10·2 | 5·8 | 5·8 | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | 1·1 | — | — | 1·4 | — |
| Magnesium Carbonate . | 3·5 | 3·15 | 3·5 | — | — | 3·65 | ·65 | — | — | — | — | ·85 |
| Magnesium Sulphate . | — | — | — | 3·75 | 3·5 | — | 6·5 | — | 4·1 | ·5 | — | — |
| Magnesium Chloride . | — | — | — | — | — | — | — | 2·0 | ·9 | 1·55 | ·95 | — |
| Sodium Carbonate . | 5·05 | 50·75 | 20·3 | — | — | 22·1 | — | — | — | — | — | 55·45 |
| Sodium Sulphate . . | 10·35 | 16·3 | 8·7 | 4·6 | 1·65 | 9·3 | 25·45 | — | — | — | — | 13·0 |
| Sodium Chloride . . | 8·9 | 244·2 | 22·45 | 3·95 | 3·95 | 33·3 | 6·6 | — | 2·5 | 1·05 | — | 65·5 |
| Sodium Nitrate . . | ·35 | ·6 | ·4 | ·15 | ·35 | ·4 | ·25 | 4·35 | ·45 | 3·0 | 4·1 | ·25 |
| | | $FeCO_3$ | | | | | $FeCO_3$ | | | | | $K_2SO_4$ |
| | | ·3 | | | | | 1·75 | | | | | 4·55 |
| Silica, &c. . . . | 2·5 | 2·7 | — | ·95 | 1·1 | 1·6 | ·55 | ·75 | ·55 | ·4 | ·65 | 1·65 |
| Total . . | 50·9 | 323·5 | 64·0 | 40·5 | 41·0 | 78·5 | 76·5 | 44·5 | 41·5 | 31·0 | 35·0 | 144·0 |
| Hardness . . . | 24° | 6½° | 9° | 23° | 25° | 10° | 32° | 30° | 27½° | 21° | 25° | 3½° |
| Free Ammonia . . | ·020 | ·160 | ·056 | ·004 | ·002 | ·080 | ·014 | ·000 | ·000 | ·003 | ·008 | ·042 |
| Albuminoid Ammonia . | ·006 | ·002 | ·003 | ·003 | ·003 | ·001 | ·003 | ·006 | ·003 | ·005 | ·004 | ·009 |
| Oxygen absorbed . . | ·013 | ·083 | ·072 | ·039 | ·029 | ·025 | ·020 | ·032 | ·014 | ·032 | ·018 | ·144 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### LIAS, 325–329. NEW RED SANDSTONE, 300–369

|  | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Crompton Durville, Somerset | Leadenham, Lincs | Stroud, Gloucester | Redcar, Yorks | Redcar, Yorks | Ilkeston, Derby | Nr. Southport, Lancs | Nr. Southport, Lancs | Nr. Warrington, Lancs | Nr. Warrington, Lancs | Leamington, Warwick | Leamington, Warwick |
| Calcium Carbonate . | 32·55 | 37·0 | 20·65 | 34·2 | 13·25 | 3·0 | 17·5 | 18·75 | 11·0 | 13·75 | 26·3 | 18·3 |
| Calcium Sulphate . . | 3·4 | 1·1 | 1·85 | — | — | — | — | — | — | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | — | — | — | ·7 | ·5 | 7·0 | 7·4 | 5·25 | 4·9 | 1·35 | 1·1 | 4·9 |
| Magnesium Sulphate . | 3·0 | 59·9 | 1·35 | 9·9 | 5·5 | — | 1·75 | 4·9 | — | 3·6 | 9·4 | 4·5 |
| Magnesium Chloride . | — | — | 1·10 | — | 1·4 | — | — | — | — | 1·2 | — | — |
| Sodium Carbonate . . | — | — | — | — | — | 13·6 | — | — | — | — | — | — |
| Sodium Sulphate . . | ·7 | 186·9 | — | 19·85 | — | — | 3·25 | — | 4·0 | — | 5·9 | — |
| Sodium Chloride . . | 4·95 | 396·0 | 1·3 | 8·25 | 5·45 | 10·5 | 4·6 | 6·3 | 2·8 | 2·45 | 3·9 | 2·65 |
| Sodium Nitrate . . | — | ·4 | 1·45 | ·25 | ·1 | — | ·35 | 1·35 | 1·2 | 2·3 | — | 1·25 |
|  |  |  |  | Fe trace |  | $BaCO_3$ 1·0 |  |  |  |  |  |  |
| Silica, &c. . . . | ·6 | — | 1·1 | 1·45 | ·8 | ·9 | ·35 | ·45 | ·9 | 1·55 | ·2 | ·4 |
| Total . . | 45·2 | 681·3 | 28·8 | 74·6 | 27·0 | 36· | 35·2 | 37·0 | 24·8 | 26·2 | 46·8 | 32·0 |
| Hardness . . . | 30° | — | 21° | 48° | 22½° | 12° | 27° | 29° | 16° | 18° | 44° | 30° |
| Free Ammonia . . | ·001 | — | ·001 | ·020 | ·004 | — | ·000 | ·001 | ·005 | ·002 | ·006 | ·003 |
| Albuminoid Ammonia . | ·003 | — | ·001 | ·002 | ·029 | — | ·000 | ·001 | ·001 | ·003 | ·003 | ·003 |
| Oxygen absorbed . . | — | — | ·008 | ·007 | ·148 | — | ·028 | ·010 | ·015 | ·028 | ·020 | ·014 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### NEW RED SANDSTONE

| Source | 337<br>Hooton, Cheshire | 338<br>Prenton, Cheshire | 339<br>Avonmouth, Gloucester | 340<br>Kirkby, Notts | 341<br>Newstead, Notts | 342<br>Bulwell, Notts | 343<br>Nr. Bulwell, Notts | 344<br>Bestwood, Notts | 345<br>Papplewick, Notts | 346<br>Nr. Newark, Notts | 347<br>Epperstone, Notts | 348<br>Nr. Retford, Notts. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate | 16·5 | 14·35 | 59·15 | 6·6 | 11·5 | 11·0 | 12·0 | 7·5 | 5·0 | 6·7 | 4·5 | 9·0 |
| Calcium Sulphate | — | — | 41·15 | — | 1·35 | 8·1 | 15·6 | ·7 | ·35 | 1·0 | — | — |
| Calcium Chloride | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate | 8·7 | 2·95 | — | — | — | — | — | — | — | — | 7·3 | 8·3 |
| Magnesium Sulphate | — | 1·25 | 77·7 | 3·0 | 5·4 | 7·9 | 2·65 | 1·0 | 1·7 | 1·05 | ·75 | 3·9 |
| Magnesium Chloride | — | — | 90·95 | 1·8 | 2·3 | 3·1 | 10·75 | 1·15 | ·4 | 2·0 | 1·9 | — |
| Sodium Carbonate | — | — | — | — | — | — | — | — | — | — | — | — |
| Sodium Sulphate | 3·8 | ·75 | — | — | — | — | — | — | — | — | — | ·45 |
| Sodium Chloride | 5·5 | 6·15 | 1069·4 | — | 1·5 | 1·15 | 6·7 | 1·9 | 2·8 | ·35 | — | 2·6 |
| Sodium Nitrate | ·25 | 1·6 | ·5 | 3·95 | 4·1 | 6·2 | 5·3 | 4·1 | 3·15 | 4·95 | $Mg2NO_3$<br>·55 | ·3 |
| Silica, &c. | ·55 | 1·35 | 11·15 | 1·15 | ·35 | 1·55 | 1·5 | ·65 | ·6 | ·95 | 2·0 | 1·45 |
| Total | 35·3 | 28·4 | 1350·0 | 16·5 | 26·5 | 39·0 | 54·5 | 17·0 | 14·0 | 17·0 | 17·0 | 26·0 |
| Hardness | 27° | 20° | 285·° | 9° | 21° | 31° | 39° | 10° | 8° | 14° | 15° | 25° |
| Free Ammonia | ·001 | ·002 | ·048 | ·000 | — | — | — | — | — | ·004 | — | ·003 |
| Albuminoid Ammonia | ·001 | ·002 | ·007 | ·005 | — | — | — | — | — | ·001 | — | ·002 |
| Oxygen absorbed | ·003 | ·005 | ·072 | ·009 | — | — | — | — | — | — | — | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### NEW RED SANDSTONE

| Source | 349<br>Cattal, Yorks | 350<br>Goole, Yorks | 351<br>Gateforth, Yorks | 352<br>Brayton, Yorks | 353<br>Selby, Yorks | 354<br>Selby, Yorks | 355<br>Nr. Selby, Yorks | 356<br>Goole, Yorks | 357<br>Burn, Yorks | 358<br>Tadcaster, Yorks | 359<br>Roall, Yorks | 360<br>Riccall, Yorks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calcium Carbonate . | 27·5 | 32·35 | 12·75 | 10·75 | 13·25 | 22·0 | 11·0 | 5·85 | 10·0 | 25·5 | 5·5 | 21·15 |
| Calcium Sulphate . . | — | — | — | — | — | — | — | 2·55 | — | 1·0 | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 2·25 | 5·4 | 3·3 | 1·45 | 5·7 | 11·25 | — | — | 3·1 | — | 3·3 | 5·45 |
| Magnesium Sulphate . | 6·9 | 6·5 | 1·75 | 2·0 | ·65 | 8·65 | 4·4 | ·75 | ·25 | 7·3 | — | — |
| Magnesium Chloride . | 3·8 | — | — | 2·15 | 2·0 | — | 1·95 | 2·55 | ·95 | ·8 | — | — |
| Sodium Carbonate . . | — | — | — | — | — | — | — | — | — | — | 4·15 | 6·35 |
| Sodium Sulphate . . | — | 5·0 | ·9 | — | — | 11·25 | — | — | — | — | 3·55 | 4·0 |
| Sodium Chloride . . | ·4 | 8·7 | 2·6 | — | 1·4 | 6·6 | ·25 | — | 1·0 | 4·05 | 3·1 | 3·8 |
| Sodium Nitrate . . | 3·3 | — | 2·05 | 4·5 | 3·2 | — | 5·5 | 3·85 | ·9 | 2·5 | 5·2 | ·9 |
|  |  | FeCO$_3$<br>·3 |  |  |  |  |  |  |  |  |  | FeCO$_3$<br>·9 |
| Silica, &c. . . . | 1·85 | 1·45 | ·65 | ·85 | ·8 | ·25 | ·9 | ·95 | 1·3 | 1·35 | ·2 | ·75 |
| Total . . | 46·0 | 59·7 | 24·0 | 21·7 | 27·0 | 60·0 | 24·0 | 16·5 | 17·5 | 42·5 | 25·0 | 43·3 |
| Hardness . . . | 34½° | 41° | 18½° | 14° | 24° | — | 16° | 12° | 15° | 30° | 12° | 25° |
| Free Ammonia . . | ·000 | ·112 | ·000 | ·003 | — | — | ·000 | — | — | ·000 | — | — |
| Albuminoid Ammonia . | ·004 | ·010 | ·002 | ·001 | — | — | ·002 | — | — | ·004 | — | — |
| Oxygen absorbed . . | ·020 | ·124 | ·012 | ·026 | — | — | ·018 | — | — | ·030 | — | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### NEW RED SANDSTONE, 361–369. COAL MEASURES, 370–372

| | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Thorne, Yorks | Thorne, Yorks | Crowle, Lincs | Crowle, Lincs | Nr. Lincoln | Nr. Lincoln | Gainsboro, Lincs | Gainsboro, Lincs | Rugeley, Stafford | Nr. Bury, Lancs | Stow-heath, Stafford | Rhymney, Glamorgan |
| Calcium Carbonate . . | 26·5 | 26·75 | 8·3 | 22·4 | 7·7 | 8·0 | 17·2 | 16·8 | 8·5 | 7·5 | 38·0 | 13·0 |
| Calcium Sulphate . . | — | — | 92·9 | — | 121·2 | 118·3 | 50·6 | 3·4 | 127·2 | 19·0 | — | — |
| Calcium Chloride . . | — | — | ·7 | — | 43·2 | 11·8 | — | — | — | — | — | — |
| Magnesium Carbonate . | 15·9 | 15·75 | — | 12·95 | — | — | — | — | — | — | 12·25 | 4·2 |
| Magnesium Sulphate . | — | — | — | 40·0 | — | — | 12·3 | 7·9 | 19·8 | 4·0 | — | 5·4 |
| Magnesium Chloride . | — | — | 30·75 | — | 62·5 | 39·5 | — | — | — | — | — | — |
| Sodium Carbonate . . | 1·05 | 5·05 | — | — | — | — | — | — | — | — | 9·45 | — |
| Sodium Sulphate . . | 2·15 | 6·2 | — | 12·3 | — | — | 36·2 | 17·5 | 9·9 | 17·8 | 79·9 | — |
| Sodium Chloride . . | 5·45 | 4·95 | 23·65 | 32·5 | 150·65 | | 7·2 | 4·6 | 2·6 | 1·65 | 17·5 | 3·0 |
| Sodium Nitrate . . | 1·05 | — | — | 21·55 | — | — | 2·5 | ·1 | 2·3 | — | — | — |
| | Fe trace | $FeCO_3$ 3·7 | Fe trace | $KNO_3$ 24·35 | KCl 11·45 | | | | | $FeCO_3$ 1·2 | | |
| Silica, &c. . . . | 1·9 | ·6 | 3·7 | 1·95 | 13·3 | — | 1·0 | 1·7 | 5·7 | 4·55 | ·9 | ·6 |
| Total . . | 54·0 | 63·0 | 160·0 | 168·0 | 410·0 | 177·6 | 127·0 | 52·0 | 176·0 | 56·0 | 158·0 | 26·2 |
| Hardness . . . | 40° | 46° | 110° | 90° | — | — | — | 26° | 110° | 30° | 43° | 20° |
| Free Ammonia . . | ·044 | ·052 | ·018 | ·000 | — | — | — | — | ·003 | — | ·026 | ·003 |
| Albuminoid Ammonia . | ·001 | ·002 | ·004 | ·014 | — | — | — | — | ·004 | — | ·003 | ·004 |
| Oxygen absorbed . . | ·020 | ·028 | ·018 | ·124 | — | — | — | — | — | — | ·006 | ·050 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

### Coal Measures

| | 373 | 374 | 375 | 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Nr. Rochdale, Lancs | Nr. Rochdale, Lancs | Rawtenstall, Lancs | Smallbridge, Lancs | Ellenrod, Lancs | Clegwood, Lancs | Nr. Rochdale, Lancs | Dearnley, Londs | Ashworth, Lancs | Cronheyshaw Coll., Lancs | Dearnley, Lancs | Severn Tunnel |
| Calcium Carbonate . . | 6·8 | 7·5 | 10·0 | 12·1 | 10·8 | 12·5 | 14·2 | 10·0 | 14·5 | 11·3 | 24·3 | 25·7 |
| Calcium Sulphate . . | — | — | — | 5·7 | — | 3·0 | — | 22·7 | — | — | 1·3 | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 5·5 | 3·65 | 2·9 | — | 2·5 | — | 5·5 | — | 3·1 | 4·4 | — | 1·0 |
| Magnesium Sulphate . | — | — | — | 9·4 | 2·75 | 9·4 | — | 9·8 | 2·0 | — | 6·9 | 8·0 |
| Magnesium Chloride . | — | — | — | — | — | — | — | — | — | — | — | 5·4 |
| Sodium Carbonate . . | 7·6 | 9·7 | 10·0 | — | — | — | 1·6 | — | — | — | — | — |
| Sodium Sulphate . . | 5·9 | 6·5 | 2·0 | 8·1 | 5·9 | 3·5 | 23·7 | 19·2 | 10·8 | 2·5 | 19·0 | — |
| Sodium Chloride . . | 3·0 | 2·0 | 2·3 | 3·0 | 2·6 | 2·6 | 2·6 | 4·0 | 2·3 | 2·6 | 5·0 | 10·8 |
| Sodium Nitrate . . | 2·1 | 1·05 | ·8 | ·55 | ·9 | 1·15 | ·75 | ·55 | ·75 | ·5 | ·3 | 1·9 |
| | | | Fe trace | Fe trace | Fe trace | Fe ·12 | Fe trace | $FeCO_3$<br>1·4 | Fe trace | | Fe trace | |
| Silica, &c. . . . . | ·7 | 1·1 | 1·9 | 2·35 | 1·55 | 1·2 | ·85 | 2·75 | 2·55 | ·7 | 1·7 | ·9 |
| Total . . | 31·6 | 31·5 | 29·9 | 41·2 | 27·0 | 33·5 | 49·2 | 70·4 | 36·0 | 22·0 | 58·5 | 53·7 |
| Hardness . . . . | 14° | 12° | 15° | 28° | 16° | 26° | 24° | 40° | 20° | 18° | 34° | 44° |
| Free Ammonia . . . | ·002 | ·002 | ·004 | ·002 | ·019 | ·064 | ·032 | ·404 | ·006 | ·003 | ·034 | ·002 |
| Albuminoid Ammonia . | ·002 | ·003 | ·002 | ·001 | ·036 | ·110 | ·004 | ·193 | ·004 | ·002 | ·002 | ·001 |
| Oxygen absorbed . . | ·003 | ·024 | ·013 | ·000 | ·130 | ·480 | ·065 | ·150 | ·080 | ·015 | ·029 | — |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

COAL MEASURES, 385–390. MILLSTONE GRIT, 391–394. MOUNTAIN LIMESTONE, 395–396

| | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Nr. Bristol | Nr. Bristol | Nr. Bristol | Nr. Bristol | Nr. Bristol | Frampton, Gloucester | Lancaster | Lancaster | Rhymney Valley | Rhymney Valley | Trefil Brook, Mon | Shon Sheffry Spring, Mon |
| Calcium Carbonate . | 33·5 | 44·5 | 17·0 | 30·5 | 31·45 | 13·05 | 14·0 | ·5 | 1·0 | 1·35 | 6·4 | 6·5 |
| Calcium Sulphate . . | — | — | — | 4·4 | 4·4 | — | — | 1·15 | 1·2 | — | — | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | — | — |
| Magnesium Carbonate . | 3·45 | 5·9 | 4·6 | — | — | 4·8 | 1·05 | — | — | — | — | — |
| Magnesium Sulphate . | — | — | — | 20·0 | 20·0 | — | — | — | ·95 | ·8 | 1·05 | 1·05 |
| Magnesium Chloride . | — | — | — | — | — | — | — | ·5 | ·3 | — | 1·1 | ·95 |
| Sodium Carbonate . . | 7·85 | 7·2 | 5·9 | — | — | 10·9 | 1·85 | — | — | — | — | — |
| Sodium Sulphate . . | 48·2 | 74·9 | 15·9 | 6·15 | 7·35 | 11·1 | 2·8 | — | — | — | — | — |
| Sodium Chloride . . | 11·55 | 21·1 | 7·2 | 5·95 | 6·1 | 5·6 | 3·8 | ·7 | 1·6 | 2·35 | 2·0 | 2·0 |
| Sodium Nitrate . . | ·2 | ·3 | ·3 | ·3 | ·3 | ·3 | ·25 | ·25 | ·1 | — | ·3 | ·25 |
| | | | | Fe trace | Fe trace | | | | | | | |
| Silica, &c. . . . | 3·35 | 1·3 | 2·1 | 2·5 | 1·6 | ·25 | 1·75 | 1·1 | ·25 | — | 1·35 | ·45 |
| Total . . | 108·1 | 155·2 | 53·0 | 69·8 | 71·2 | 46·0 | 25·5 | 4·2 | 5·4 | 4·5 | 12·2 | 11·2 |
| Hardness . . . | 40° | 53° | 22° | 60° | 60° | 18° | 19° | 2° | 3·5° | 2° | 7° | 7° |
| Free Ammonia . . | ·036 | ·030 | — | ·003 | ·000 | — | ·128 | ·002 | ·000 | ·001 | ·011 | ·000 |
| Albuminoid Ammonia . | ·008 | ·002 | — | ·004 | ·004 | — | ·002 | ·006 | ·003 | ·011 | ·022 | ·006 |
| Oxygen absorbed . . | ·071 | ·022 | — | ·002 | ·026 | — | ·007 | ·118 | ·031 | ·154 | ·358 | ·106 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

MOUNTAIN LIMESTONE, 397–404. OLD RED SANDSTONE, 405–6. OLDER ROCKS, 407–408

|  | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Nr. Pontypool, Mon. | Bakewell, Derby | Mallow, Cork | Carrick | Clonmel | Knocklong | Tipperary | Greybridge | Middleton, Cork | Above Pontypool | Kelso, N.B. | Floors Castle, Kelso |
| Calcium Carbonate . | 9·0 | 18·5 | 10·65 | 25·3 | 19·85 | 23·2 | 26·0 | 28·5 | 4·6 | 7·5 | 19·2 | 1·25 |
| Calcium Sulphate . . | — | 37·4 | 5·9 | — | — | — | — | — | — | — | 39·7 | — |
| Calcium Chloride . . | — | — | — | — | — | — | — | — | — | — | 142·9 | — |
| Magnesium Carbonate . | ·85 | — | — | 2·8 | 1·5 | 4·85 | 2·8 | 4·15 | ·6 | 4·8 | — | ·15 |
| Magnesium Sulphate . | 1·75 | 11·1 | 3·8 | 1·45 | 1·50 | — | 3·3 | — | ·8 | — | — | — |
| Magnesium Chloride . | — | 1·2 | — | — | — | — | — | — | ·8 | — | 62·6 | — |
| Sodium Carbonate . . | — | — | — | — | — | 1·85 | — | — | — | — | — | 25·15 |
| Sodium Sulphate . . | ·6 | — | — | 1·35 | — | 2·25 | ·85 | 1·2 | — | 2·8 | — | 1·95 |
| Sodium Chloride . . | 2·0 | 2·95 | 5·35 | 4·3 | 3·0 | 5·0 | 6·25 | 4·8 | 2·3 | 2·0 | 721·2 | 3·45 |
| Sodium Nitrate . . | ·8 | — | 7·8 | 1·1 | ·9 | 2·75 | 2·2 | ·9 | 1·6 | ·2 | — | ·4 |
| Silica, &c. . . . | ·8 | 1·85 | 1·3 | ·9 | ·45 | 1·1 | 1·2 | ·45 | ·1 | ·5 | 4·4 | 2·15 |
| Total . . | 15·8 | 73·0 | 34·8 | 37·2 | 27·2 | 41·0 | 42·6 | 40·0 | 10·8 | 17·8 | 990·0 | 34·5 |
| Hardness . . . | 11° | 60° | 21° | 32° | 21° | 32° | 32° | 28° | 7° | 12° | — | 2° |
| Free Ammonia . . | ·000 | — | ·001 | ·006 | ·002 | ·002 | ·005 | ·001 | ·001 | ·001 | — | ·010 |
| Albuminoid Ammonia . | ·011 | — | ·007 | ·004 | ·001 | ·002 | ·002 | ·001 | ·006 | ·002 | — | ·004 |
| Oxygen absorbed . . | ·170 | — | ·047 | ·040 | ·040 | ·020 | ·020 | ·000 | ·053 | ·020 | — | ·052 |

## RESULTS OF WATER ANALYSES, IN PARTS PER 100,000

OLDER ROCKS, 409–410. AFRICA, &c., 411–419.

| | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Malvern | Llandrindod, Wells | Damaraland | Zanzibar | Zanzibar | Zanzibar | Zanzibar | Morocco | Morocco | Singapore | Australia |
| Calcium Carbonate . . . | 9·15 | 14·8 | 44·5 | 1·25 | 26·15 | 26·75 | 21·50 | 40·0 | 53·5 | 5·8 | 21·5 |
| Calcium Sulphate . . . | — | 9·8 | — | — | — | — | — | 31·1 | 40·5 | — | — |
| Calcium Chloride . . . | — | 158·4 | — | — | — | — | — | 52·9 | 18·0 | — | — |
| Magnesium Carbonate . . | 1·45 | — | 38·4 | ·2 | 2·05 | 1·75 | 1·55 | — | — | — | 23·1 |
| Magnesium Sulphate . . . | 4·0 | — | — | — | — | — | 2·0 | — | — | — | — |
| Magnesium Chloride . . . | ·5·15 | 53·9 | — | — | — | — | 4·15 | 29·3 | 26·5 | — | — |
| Sodium Carbonate . . . | — | — | 9·7 | 2·2 | ·8 | ·85 | — | — | — | 1·0 | 27·55 |
| | | | $K_2SO_4$ | | | | | | | $K_2SO_4$ | |
| Sodium Sulphate . . . | — | — | 9·05 | ·75 | ·45 | ·6 | — | — | — | 5·35 | 18·5 |
| Sodium Chloride . . . | 6·8 | 233·8 | 5·3 | 2·0 | 2·65 | 2·65 | 21·25 | 85·0 | 16·2 | 68·0 | 105·6 |
| Sodium Nitrate . . . . | 1·0 | NaBr | 1·3 | ·3 | ·4 | ·5 | ·6 | 87·0 | 37·7 | ·2 | 1·8 |
| | | ·85 | | | | | | | | $SiO_2$ | |
| | | $Fe_2CO_3$ | | $SiO_2$ | | | | | | 11·0 | |
| | | 2·3 | | ·10 | | | | | | &c. | |
| Silica, &c. . . . . . | ·05 | 19·15 | 1·75 | 3·4 | 1·5 | 2·5 | 1·95 | 9·7 | 5·6 | 1·15 | 1·55 |
| Total . . . . | 27·6 | 493·0 | 110·0 | 10·2 | 34·0 | 35·6 | 53·0 | 335·0 | 198·0 | 92·5 | 199·6 |
| Hardness . . . . . . | 19° | — | +80° | 2° | 26° | 27° | 26° | +140° | 130° | 5° | — |
| Free Ammonia . . . . . | ·006 | — | ·050 | ·002 | ·000 | ·000 | ·000 | ·015 | ·021 | ·000 | — |
| Albuminoid Ammonia . . | ·008 | — | ·020 | ·003 | ·000 | ·000 | ·001 | ·047 | ·059 | ·000 | — |
| Oxygen absorbed . . . | ·072 | — | ·200 | ·110 | ·012 | ·012 | ·000 | — | — | ·000 | — |

# CHAPTER XIX

## THE BACTERIOLOGICAL EXAMINATION OF WATER

The media referred to in this section should be prepared according to the formulæ given in the appendix. No uniformity is attainable without the use of standard media, and as my results are based upon experiments in which the solid and liquid media described there were employed, it cannot be taken for granted that results obtained by other methods or with other media will admit of similar interpretation.

It is also assumed that no one will attempt the bacteriological examination of waters, who has not previously acquired experience in technique in a properly equipped laboratory and under the guidance of a competent instructor. For this reason, it is unnecessary to describe the apparatus found in every laboratory, or to give all the details of the comparatively simple processes used in the routine method of water examination.

Bacteriological examinations are in the great majority of cases undertaken either for the puropse of ascertaining the efficiency of some filtering arrangement, or for the detection of pollution derived from sewage or of manurial origin. For both these purposes it is desirable to ascertain approximately the number of bacteria present in the sample of water under examination, and to make a search for certain organisms, the presence of which, either alone or in association in the water, would imply that it was more or less contaminated. The smaller the amount of water in which such organisms can be detected, the greater the pollution, and *vice versa*.

With reference to the enumeration of the bacteria present in a given quantity of a water (1 c.c. is the amount universally adopted) I have already stated that it does not, in itself, furnish information of any great importance, and this was on the assumption that the number could be ascertained with a fair degree of accuracy, and that the results obtained by different bacteriologists would be fairly comparable. Notwithstanding all that has been written about the precautions to be taken to obtain comparable results, those obtained by different bacteriologists examining the same waters vary considerably. As an illustration of this discrepancy, I may compare the results obtained in my own laboratory with those from another well-known London laboratory where the same series of carefully collected samples were being examined at the same time. It will be seen that there is no kind of agreement between them.

Number of Organisms per c.c.

| | Lab. A | Lab. B |
|---|---|---|
| No. 1. | 12 | 152 |
| No. 2. | 13 | 48 |
| No. 3. | 15 | 260 |
| No. 4. | 25 | 250 |
| No. 5. | 95 | 164 |
| No. 6. | 108 | 240 |

I could quote many such instances, some exhibiting even greater discrepancies. It is not surprising therefore that sanitary authorities doubt the infallibility of bacteriologists when such discrepancies occur in their results. The variations which occur in chemical analyses made in different laboratories are usually very slight, and not at all comparable with those found in bacteriological work.

It is a well-known fact that the nature of the medium, its reaction, the duration of incubation, and the temperature are all important factors in the development of water bacteria, yet no standard is generally adopted. There is no standard medium, reaction, period of incubation, &c. Some count only colonies visible on the third day, others those visible on the fourth or even the fifth day, some again use a lens or the low power of a microscope for counting purposes, others enumerate only those visible to the naked eye. It is probable that this difference in the mode of counting is the chief cause of the discrepancy so often observed.

In some cases the colonies develop so slowly that few are visible to the naked eye on the third day. A plate which has been incubated for three days may show a dozen small colonies to the naked eye, yet by aid of a lens hundreds of minute colonies can be counted. It is very easy to understand how in such a case different observers would record different results.

It is desirable to avoid stating that a given water contains a certain number of organisms per c.c., since such a determination is practically impossible. There may be many bacteria present which refuse to grow in, or on, the particular media employed; hence it is more accurate and scientific to state the number of colonies which grow from 1 c.c. of the water on a certain nutrient jelly after so many days' incubation at a given temperature, and to avoid misconception it would be well to add whether the colonies included only those visible to the naked eye, or all visible under a certain magnifying power.

### A. DETERMINATION OF THE NUMBER OF ORGANISMS PRESENT IN 1 C.C. OF WATER WHICH ARE CAPABLE OF GROWING AT 20° C. IN THREE DAYS, UPON NUTRIENT JELLY HAVING A + 1 ACID REACTION

Ten c.c. of the nutrient jelly recommended (Formula 57) are used for each plate or petri dish. To one tube of jelly 0·5 c.c. of the water is added, to another 1 c.c. The water should be well agitated before taking out the sample, as the bacteria may be adherent or even in zoogl&oelig;a masses. It does not appear to be either necessary or desirable to use larger or smaller quantities of water. If the colonies which grow on the 0·5 c.c. plate are exceedingly numerous, their exact enumeration would be a mere waste of time; and on the other hand, however few bacteria may be present 1 c.c will suffice for their enumeration, and the results obtained with 0·5 and 1 c.c. are more comparable than those obtained when smaller quantities are used. The petri dishes used should be placed within a large dish, the bottom of which is covered with thick blotting-paper well moistened with 0·1 per cent. solution of mercuric chloride. This prevents any excessive evaporation and the consequent drying of the thin plate of jelly. Incubate at 20° C. and count the number of colonies at the end of the third day by aid of a pocket lens having a focal length of 1½ in. Should many liquefying colonies be present, the counting may take place earlier, but if so the fact should be stated. Such a necessity rarely arises save when the water is of doubtful quality.

When every care is taken, cases occur in which different observers examining the same plate obtain markedly different results. Many colonies are so minute and transparent that they can only be discovered when the light falls upon them at a special angle. If the jelly is not perfectly bright, the suspended particles will increase the difficulty of making an accurate count.

### B. DETERMINATION OF THE NUMBER OF BACTERIA PRESENT IN 1 C.C. OF THE WATER, CAPABLE OF GROWING ON AGAR MEDIUM AT 37° C. IN TWENTY-FOUR HOURS

The agar medium, 10 c.c., is melted by immersion in boiling water, and then cooled down to 42° C. As soon as it has reached this temperature, 0·5 c.c. of the water may be placed in one tube and 1 c.c. in another, and after each has been mixed they are poured into separate petri dishes (preferably warmed to 42° C.) and further admixture secured by sloping the plates at various angles. When set, the dishes should be placed in the warm incubator, with the covers partly off to allow the surface of the agar to dry. Then put on the covers and invert the plates. Count the colonies at the end of twenty-four hours.

Some bacteriologists also make plates with neutral-red bile-salt glucose agar, or similar agar containing lactose instead of glucose. Occasionally Drigalski and Conradi's medium is used.

The object of this procedure is to limit the growth as far as possible to organisms of so-called 'intestinal' type. For research purposes the results may be useful, but they are of no service in a routine examination of water from diverse sources. When samples of water from the same source are being frequently examined for comparative purposes the results may be distinctly useful, as any marked change in the water is detected in twenty-four hours. The same result, however, is practically obtained in the same time by the presumptive test for the Bacillus coli. In enumerating bacteria by any method, a note should be made as to whether the sample had been packed in ice or not, and as to any circumstance which might have caused any change in the bacterial contents during transit.

If the water contains the Bacillus mycoides, the agar plates may be more or less completely covered with its growth in twenty-four hours, and vitiate the results. It is unusual, however, for both plates to be so affected that a count cannot be obtained. The dendriform growth of the B. mycoides should only be counted as one colony.

### C. DETECTION OF COLON BACILLI. 'PRESUMPTIVE' TESTS

In the following paragraphs, microbes which are capable of producing acid in glucose broth in the presence of bile-salts (MacConkey's fluid) are referred to as being of the intestinal type. These organisms are so abundant in all sewages and manurial matter that if their absence in a given quantity of water is determined, it may be affirmed that no polluting matter derived from such sources is present, or that the amount of pollution is so small as to be incapable of being detected by bacteriological methods.

In examining a water, therefore, the search should first be directed towards the detection of the presence of organisms of the intestinal type. If these are absent, the examination need not proceed further. If present, pollution is indicated, but it must be remembered that there are organisms capable of fermenting glucose and even lactose, which are in no way characteristic of sewage or excremental matter, and that these may occur in waters free from admixture therewith; hence the investigation must be carried further before an opinion can be expressed with reference to the absence or presence of polluting matter derived from such sources.

Several tests have been proposed for obtaining an indication of the presence or absence of groups of organisms which are rarely found in waters of known purity, but which invariably are present in sewage-polluted waters. In all such tests varying quantities of the water, or of the bacterially concentrated water, are added to some special medium and the effects produced during incubation noted. The tests chiefly used are:

MacConkey's, using bile-salt litmus glucose broth.
Parietti's, using phenolated broth.
Houston's, or the shake gelatine test.
The neutral-red test.

My experience tends to prove that the bile-salt test is the most useful; it may therefore be considered first.

(1) **MacConkey's Test.**—This was first suggested by Drs. MacConkey and Hill, the Assistant Bacteriologists to the Royal Commission on Sewage Pollution, and consists in adding, to varying quantities of the water, bile-salt glucose peptone litmus solution, and incubating at 36°–37° C., or preferably at 42° C. for twenty-four hours.

The organisms which can grow in this medium may be divided into three classes:

1. Those producing acid and gas.
2. Those producing acid but no gas.
3. Those producing a turbidity merely.

If the microbes present, as is very frequently the case with pure waters, are not capable of growing in this solution, of course the broth remains clear after incubation. Interest chiefly centres in the first group, as this includes all the more important organisms found in sewage. Those included in the second group may also be organisms of intestinal type, but inasmuch as, if present, they would be associated with a far larger number of others belonging to group 1, it is not necessary to examine any water further if it does not contain organisms capable of producing acid and gas in this medium. Group 3 includes few, if any, organisms which can be said to be of intestinal origin and may also be ignored.

The known organisms which produce acid or acid and gas in bile-salt glucose broth are given in the following Table:

GROUP 1

Producing acid and gas

Bacillus coli communis.
„ enteritidis (Gaertner).
„ acidi lactici.
„ cavicida.
„ neapolitanus.
„ capsulatus.
„ lactis aërogenes.
„ icteroides.
„ paracolon.
„ pneumoniæ.
„ cloacæ.

GROUP 2

Producing acid, but no gas

Bacillus typhosus.
„ pyogenes fœtidus.
„ dysenteriæ.
„ choleræ.
„ prodigiosus.
Proteus vulgaris.
Staphylococcus aureus.
„ albus.
„ citreus.

MacConkey and Hill appeared to think that the reaction of group 1 alone was sufficient to prove the absence or presence of sewage contamination, and they quote the following experiments in proof thereof. Waters from different sources were examined by this test, and afterwards those which gave a positive reaction were further investigated to ascertain if the Bacillus coli communis could be detected. In each case, 1 c.c. of the water was added to each of three separate tubes of solution. Dilutions of sewage varying from 1 in 10 to 1 in 1,000,000 were similarly treated. The tubes were incubated at 42° C. for forty-eight hours.

The results obtained were as follows:

I. DRINKING WATERS

| — | Moorland filtered water | Filtered rain water | River water |
|---|---|---|---|
| No. of samples examined . . . . . | 118 | 169 | 41 |
| No. giving reaction . . . . . . | 5 | 16 | 41 |
| No. found to contain the B. coli communis . | 5 | 16 | 41 |

II. SAMPLE OF SEWAGE.

Positive result in every instance.

In every case in which a positive reaction was obtained the water was subsequently found to contain the Bacillus coli communis (?), but Dr. MacConkey has since found that the test is not so conclusive as he at first believed. As a matter of fact, it is merely a 'presumptive' test, and is now only regarded as such.

It has been recommended to substitute lactose for the glucose in the original medium, in order to effect a more definite differentiation. I prefer to use the solution originally recommended, and to effect the further differentiation at a later stage; but when time is important it is often convenient to use the lactose medium in the first instance, especially if the sole information required is whether the water contains bacilli of the Colon group. I like, however, to know whether even glucose fermenters are present, and whether they are as abundant as, or more abundant than, the lactose fermenters. Waters of the very highest class contain few or none of either. It is possible also that attenuated members of the Colon group will grow in the glucose broth and not in the lactose broth, and after passage through the glucose medium will then grow in the lactose. My chief reason for adhering to the use of the bile-salt glucose, in the first instance, is that this and the following incubation kills off nearly all the organisms belonging to other groups and simplifies the subsequent examination.

## D. The Presumptive Test for Colon bacilli

The test is carried out in the following manner in my laboratories: Four test-tubes of suitable dimensions, and each containing 10 c.c. of bile-salt glucose broth of the requisite strength (*vide* Formulæ 49–52), are taken. To the weakest 1 c.c. of the water is added, to the next 5 c.c., to the third 10 c.c., and to the fourth 20 c.c., making a total of 36 c.c. For river-derived waters, surface waters, and shallow well waters, this quantity suffices; but for deep well waters and occasionally for waters from other sources, 64 c.c. is also put on in a flask containing 30 c.c. of the most concentrated broth. The result is that 100 c.c. is then examined.

Some may prefer to prepare three tubes of each dilution, 1, 5, 10, and 20 c.c., in which case a total of 106 is used. The advantage of this will be referred to later.

The tubes and flasks are placed in the incubator at 37° C., and those which show the presence of acid and gas in twenty-four hours are removed for further examination. Where one or more tubes show vigorous gas formation and one of the smaller quantities shows only a slight tendency to produce gas, the latter may be incubated for a further period of twenty-four hours. If all the results are negative, it is obvious that the examination need not be carried further, since bacteria of the Colon type cannot be present in the amount of water examined. In the great majority of cases, if one tube shows the presence of gas, all the tubes containing larger quantities will show it also ; but on rare occasions, one of the tubes may give negative results, due to the accident of the particular volume of water taken not containing a bacillus capable of causing fermentation. If only one out of the whole series shows the presence of gas, then it may be taken that the whole volume of water used in the experiments only contained one such bacillus.

If three tubes are made of each dilution, then, whenever two out of three tubes show that fermentation is taking place, the 'presumptive' result is said to be positive with the amount of water contained in each tube.

The production of acid only is without significance, but waters of the very highest type of purity do not contain organisms capable of producing acid in this medium. The mere presence of organisms producing fermentation cannot be regarded as any proof of dangerous contamination, since many waters of undoubtedly good quality give the 'presumptive' reaction, yet do not contain any Colon bacilli in the quantities usually examined.

In the United States it is almost the rule to inoculate each of ten bile-salt broth tubes with 1 c.c. of the water to be examined, and to judge of the quality of the water by the results. If no fermentation takes place in any tube, the water is regarded as quite satisfactory. If it takes place in all, the water is decidedly 'bad,' and the smaller the number of tubes showing the production of gas, the better the water. In many cases, however, I believe lactose is substituted for glucose, which results in making the test still less stringent. A broth made from liver instead of from bile-salts is strongly recommended by the American Public Health Association.

(2) **Parietti's Test.**—In this method a nutrient broth containing 0·05 to 0·1 per cent. of phenol is used for inhibiting the growth of other than bacteria of intestinal type. I have made many comparative tests and find the bile-salt broth much the more reliable—in fact, the test has been completely superseded and it is now rarely, if ever, used. Further reference is therefore unnecessary.

(3) **Houston's Gelatine 'Shake' Test.**—Houston appears to lay much stress on the production of gas in gelatine 'shake' cultures, varying quantities of water being used and the incubation taking place at 20° C.

In his Report to the Medical Officer of the Local Government Board (Report 1899–1900, p. 487), he says:

'The gas-producing property of certain bacteria has been for long utilised as a test in one way or another by different bacteriologists. The sense in which I would here advocate this test may be briefly outlined as follows:—

'From a long series of experiments I have found that in sewage, B. coli (or closely allied forms) and a microbe, which I have described under the name of "sewage proteus," are present in crude sewage in numbers usually exceeding 100,000 per c.c. This "sewage proteus" (and its close allies), just like B coli, produces "gas" in gelatine "shake" cultures in twenty-four hours at 20° C. It is evident, then, that it might be anticipated that the addition of sewage directly to gelatine would produce "gas" in "shake" culture, provided that these microbes were present in sufficient numbers. Such a biological test could hardly be considered scientific in the absence of records to show (*a*) that the most numerous gas-forming bacteria in sewage belong to the objectionable coli and proteus class, and (*b*) that a parallelism exists between the numbers of B. coli and sewage proteus and the amount of liquid required to produce a gaseous change.

'In my experience both these things are true, although it is to be noted that a larger quantity of sewage is required to form "gas" when added directly to the gelatine than the actual number (as ascertained by plate culture) of B. coli and B. proteus would lead one to expect. As a matter of fact, the test is about one hundred times less delicate (although still very delicate) than the enumeration of B. coli and B. proteus by plate culture. Usually about $\frac{1}{1000}$ c.c. of sewage is required to produce "gas" in gelatine "shake" culture in twenty-four hours at 20° C., whereas, as has been stated, gas-forming B. coli and B. proteus are commonly present in $\frac{1}{100000}$ c.c. of sewage. So that the absence of "gas" in twenty-four hours in gelatine (at 20° C.), to which, say, $\frac{1}{1000}$ c.c. of sewage had previously been added, would not imply the absence of the microbes from this amount of sewage, but only that they were not present in sufficient numbers to produce a visible development of "gas." The test may be rendered more delicate by extending the time up to forty-eight hours or even longer; but I have not, for various reasons, found this advisable unless when dealing with potable waters, and when the result is negative in twenty-four hours. Although unquestionably, in my experience, there is a broad parallelism between the number of B. coli and B. proteus in a substance, and the amount of that substance necessary to effect a gaseous change in gelatine, it must not be supposed that the agreement is an absolute one. Yet such discrepancies, as do occur, need not be regarded as so pronounced as to seriously impair the value of the test as a "rough and ready" biological method of comparing different substances in respect of these objectionable bacteria.

'As a rapid and simple method of forming an opinion of the extent to which biological purification has been carried in the case of polluted rivers and sewage effluents the test is one of considerable value.

'There is some reason to suppose that B. coli and B. proteus, outside the animal body and under natural conditions, may in course of time lose their original gas-producing property or retain the ability in diminished degree. But if this be true, is it not also probably the case that they and other correlated germs of excremental sort are the less to be thought of as noxious or dangerous in character, by reason of loss of their original properties as the result of a too long separation from their initial animal surroundings ? '

To apply this test it is necessary to concentrate the bacterial contents of a considerable quantity of water, 100 c.c. or more, in the manner described in the section relating to the detection of the B. enteritidis sporogenes of Klein. The final 5 c.c. of water contained within the filter candle, after brushing, will contain all the organisms in the quantity of water originally taken.

Take five tubes of gelatine medium. To one add 1 c.c. of the original water, to a second 0·25 c.c. of the filter brushing, to a third 0·5 c.c., to a fourth 1 c.c., to a fifth 2 c.c. These tubes will contain the bacteria in 1, 5, 10, 20 and 40 c.c. of water respectively, and of 76 c.c. collectively, assuming 100 c.c. to have been used originally.

Solidify and place in the incubator at 20° C. for twenty-four hours. The smaller the quality of water causing the production of gas bubbles in the jelly, the more likely is the water to prove to be polluted. This production of gas must not, by itself, be taken as proving that the water is dangerously contaminated, or even polluted at all with sewage matter, but merely as indicating that certain microbes are present which may have been derived from sewage or manure.

(4) **The Neutral-red Test.**—In 1898 Rothberger showed that if a little neutral red were added to tubes containing glucose media, and these were inoculated with the Bacillus coli communis, after from twenty-four to thirty-six hours' incubation, the colour became greenish-yellow and markedly fluorescent. As the Bacillus typhosus produces no such change, he recommended this process as a ready means of distinguishing between the two. Many observers have since endeavoured to make this test available in the examination of water for the detection of

the B. coli, notwithstanding that it is known that other organisms found in soil and in potable waters possess the power of reducing neutral-red with the production of fluorescence.

Dr. Makgill[1] found that, using bouillon, the reaction could be constantly obtained within twenty-four hours, even with dilutions corresponding to from 1 to 5 B. coli per c.c. As the result of his experience, he concluded that a negative result justified the conclusion that the B. coli was absent, but he would not assert that a positive reaction always denoted the presence of that organism.

Dr. Savage, in discussing the use of neutral-red in the routine examination of water,[2] lays stress on the strength of the neutral-red media employed. If too much is used the organisms present may not be able to reduce it, and he recommends that to get the best results 0·1 c.c. of a 0·5 per cent. watery solution of neutral-red (Grübler's) should be added to 10 c.c. of broth or agar. He examined fifty waters from different sources. Ten of these, which gave no reaction with the neutral-red, on further examination appeared to be free from the B. coli. Of thirty-nine samples giving a positive reaction, thirty-four were further examined and the bacilli found in thirty-one. The results of forty-seven examinations are given in the following table:

| General character of water | No. of samples | Neutral-red reaction | | B. coli looked for | | B. coli found | |
|---|---|---|---|---|---|---|---|
| | | + reaction | − reaction | with + reaction | with − reaction | with + reaction | with − reaction |
| Bad . . | 25 | 25 | 0 | 20 | 0 | 20 | 0 |
| Good . . | 19 | 9 | 10 | 9 | 9 | 7 | 0 |
| Suspicious . | 3 | 2 | 1 | 2 | 1 | 2 | 0 |
| Totals . | 47 | 36 | 11 | 31 | 10 | 29 | 0 |

In these experiments Dr. Savage used from 1 to 40 c.c. of water, and the conclusions he arrived at are as under:

'1. A positive neutral-red reaction, obtained as above, whilst not absolutely diagnostic of the B. coli, yet in the vast majority of cases points to the presence of that organism.

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[1] *Journal of Hygiene*, 1901, No. 3.

[2] *Ibid*, vol. i. p. 437.

'2. A negative neutral-red reaction obtained as above does not entirely exclude B. coli, but renders its presence highly improbable.

'3. The neutral-red test is very readily applied, and, with reasonable care, fallacies in its employment can be avoided.

'4. It is a test which is of great value in the routine examination of a water.'

Reviewing the results obtained with the potable waters examined, he says: 'The results are somewhat surprising, and tend to make me reconsider the significance of the presence of the B. coli in water. The detection of the organism in all the obviously bad waters points strongly to its association with contamination.'

The method adopted by Dr. Savage was to add 10 c.c. or less of the water to 10 c.c. of the neutral-red broth, and to add to 40 c.c. of the water 10 c.c. of the neutral-red broth of four times the ordinary strength.

As the result of further experience, Dr. Savage[1] says: 'The neutral-red method, as shown by the writer and confirmed by Gage and Philips, is a fairly sensitive "preliminary" test, at least, for certain classes of water. As a "presumptive" test alone and without isolation of the coliform organism, it is unreliable and should not be used.' With this opinion my experience enables me cordially to agree. It is practically useless, and may be very misleading.

### E. Confirmatory Test for Colon bacilli.

This test is of the simplest character. From each tube giving a positive reaction with the preliminary test, a tube of lactose bile-salt broth is inoculated. These are placed in the incubator and kept at 37° C. for twenty-four hours (in case of doubt for forty-eight hours), and those in which acid and gas are produced are regarded as answering the 'confirmatory' test. On occasions the smallest quantity of water which answered to the preliminary test will answer to the confirmatory test, but in the majority of cases only the larger quantities respond. This in itself is not without significance since it shows, as does sewage, that the lactose fermenting bacteria are associated with others which, though they cannot ferment lactose, can break down glucose with the production of acid and gas.

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[1] *The Bacteriological Examination of Water*, p. 231.

### F. DECISIVE TESTS FOR THE PRESENCE OF COLON BACILLI.

These tests necessitate the isolation of individual bacteria growing in the lactose broth. A plate may be made in the first instance, from the tube corresponding to the smallest quantity of water which responded to the confirmatory test, but if the colonies so obtained do not prove to belong to the Colon group, then the broths corresponding to the larger quantities of water must also be examined.

For isolating the bacteria, neutral-red bile-salt agar is the best medium for general use, but some prefer to use phenolated gelatine or Drigalski and Conradi's medium.

The latter are useful for certain purposes, but not nearly so useful for routine work in water analysis as the bile-salt agar. In this medium the Colon bacilli grow freely, the resulting colonies having a dull-red colour and being surrounded by a haze due to the precipitation of the bile acids. This haze, however, may not appear for forty-eight hours or more, depending in great part, but not entirely, on the quality of the medium. Some batches appear to be more responsive than others, which, so far as one could tell, have been prepared exactly in the same way.

To isolate the organisms growing in the fluid medium, transfer a loopful to about 10 c.c. of sterile water, and after agitation diffuse a droplet of the mixture over a recently poured plate of neutral-red agar (Formula 54) by means of a platinum rubber or glass spreader. Incubate at 36–37° C. for twenty-four hours, and examine.

On rare occasions no growth whatever will be obvious, in which case the examination need not be carried further, as there are no organisms present which belong to the Colon groups. Occasionally the growth may consist entirely of small white colonies; frequently there are both red and white colonies, the former predominating, but usually there are red colonies only. The red colonies alone need be considered. These vary somewhat in appearance, some being wholly red, others only red towards the centre, the peripheral portion being of a creamy white.

It is not necessary to wait to ascertain whether any haze is produced, but simply to select one or more of the red colonies for the further examination. If all the colonies appear alike one only may be taken, but it is better to select and examine three.

Make an emulsion from each in about 5 c.c. of sterile water, and with this mixture inoculate (1) a tube of litmus milk, (2) a tube of peptone solution. Incubate at 37° C.

These are all which are really necessary, but the following tests may also be applied with advantage:

(3) Examine in a hanging drop to ascertain whether the bacillus is motile or not.

(4) Stain by Gram's method and note whether the stain is retained or not.

(5) Make a streak culture on gelatine and place in the cool incubator for seven to fourteen days to ascertain whether the growth liquefies the gelatine, and whether it corresponds in appearance with that of the B. coli.

(6) Inoculate a tube of neutral-red broth or neutral-red agar, for the production of fluorescence.

(7) Inoculate sucrose broth.

(8) Inoculate mannite broth.

(9) Inoculate dulcite broth.

Other sugars may also be experimented with.

If acid is produced in the milk within twenty-four hours and the milk is curdled within three days, and if indol is produced in the peptone solution within the same period, the bacillus under examination may definitely be said to belong to the Colon group. A further differentiation may be made from the results of any additional tests applied, but the results are, at present, of little practical value. Probably the greater the number of varieties, the greater the certainty of their being derived from sewage.

The members of the Colon group which clot milk and produce indol are the most common in sewage, and if none of the colonies examined give these reactions the water cannot be said to contain bacteria of the Colon group.

The peptone solution is examined for indol by the addition of about one-tenth its volume of a solution of paradimethylamidobenzaldehyde, and the same quantity of a saturated solution of potassium persulphate (*vide* formula). A red colour develops more or less rapidly according to the amount of indol present. This is a far more delicate reaction than that with sodium nitrite and sulphuric acid. If the milk has rapidly curdled and time is of importance, the test may be applied to the peptone solution on the second day. If there is no reaction, the remainder of the solution should be returned to the incubator and be examined at the end of the third day.

The following Table will show the kind of results obtained by this method of examination. The 'decisive' tests referred to are the production of acid and clot in milk, and of indol in peptone solution. The last 100 samples of water examined in my London laboratory, which gave the 'presumptive' reaction for the Colon bacilli are arranged in order of time only. They were derived from all parts of the country and from the most diverse sources. In some, 100 c.c. of water was used for the examination; in others, only 36 c.c.

The Table shows:

(1) That in 74 per cent. of the samples which gave positive results with the 'presumptive' test the Colon bacilli were found in the quantity of water taken for the examination.

(2) That in 75 per cent. of the samples the 'presumptive' result was substantiated by the 'confirmatory' results.

(3) That in nearly 99 per cent. (74 out of 75) of the waters giving positive results with the 'confirmatory' test the Colon bacilli were found in the quantity of water examined.

(4) That in 24 per cent. the 'confirmatory' and 'decisive' results were obtained in the minimum quantity of water, giving a positive reaction with the 'presumptive' test.

(5) That in a further 43 per cent. positive 'decisive' results

were obtained from the same minimum quantity of water as the positive ‘confirmatory’ results.

(6) That in 5 per cent. of the samples positive decisive results were obtained only with larger quantities of water than the minimum required for the positive ‘confirmatory’ results.

In other words, if a water answers to the ‘presumptive’ test for the Colon bacilli, the probability of its containing these bacilli is 3 to 1; if the water also responds to the ‘confirmatory’ test, the probability of its containing Colon bacilli is 99 to 1.

Table of 100 Waters showing the Quantities giving the ‘Presumptive,’ ‘Confirmatory,’ and ‘Decisive’ Reaction for B. coli

| P. | C. | D. | P. | C. | D. | P. | C. | D. |
|---|---|---|---|---|---|---|---|---|
| 1 | 20 | 20 | 10 | 10 | 10 | ·1 | 60 | 60 |
| 1 | 10 | 20 | 1 | 5 | 5 | 1 | 1 | 1 |
| 1 | 20 | 20 | ·1 | ·1 | ·1 | 5 | 10 | 10 |
| 5 | 5 | 5 | ·01 | ·01 | ·01 | 1 | 5 | 5 |
| 1 | 1 | 5 | 5 | 10 | 10 | 1 | 1 | 1 |
| 20 | —36 | —36 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 10 | 10 | 1 | 5 | 5 | ·01 | ·1 | ·1 |
| 5 | —36 | —36 | 1 | 5 | 5 | 5 | 5 | 5 |
| 20 | —36 | —36 | 1 | 1 | 1 | 20 | —100 | —100 |
| 5 | 10 | 10 | 1 | 5 | 5 | 20 | —100 | —100 |
| 5 | 5 | 5 | 10 | 100 | 100 | 5 | 5 | 10 |
| 5 | —36 | —36 | 1 | 1 | 1 | 5 | 10 | 10 |
| 5 | 20 | 20 | 1 | 5 | 5 | 10 | 20 | 20 |
| 5 | —36 | —36 | ·1 | ·1 | ·1 | 5 | 5 | 5 |
| ·1 | ·1 | ·1 | 1 | 10 | 10 | 5 | 5 | 5 |
| 1 | 1 | 1 | 1 | 10 | 10 | ·1 | 5 | 5 |
| 5 | —36 | —36 | 5 | 20 | 20 | 10 | 60 | 60 |
| 20 | —100 | —100 | 5 | —36 | —36 | 1 | 1 | 5 |
| 1 | 1 | 1 | 5 | 10 | 10 | 10 | 10 | 10 |
| 1 | 1 | 1 | 5 | —36 | —36 | 5 | 60 | 60 |
| 1 | 1 | 1 | 5 | 10 | 10 | 5 | 60 | 60 |
| 5 | 10 | 10 | ·1 | 20 | 20 | 5 | —36 | —36 |
| 10 | 20 | 20 | ·1 | 10 | —36 | 10 | —36 | —36 |
| 1 | 1 | 1 | 5 | —36 | —36 | 10 | —36 | —36 |
| 1 | 5 | 5 | 10 | —36 | —36 | 60 | —100 | —100 |
| ·1 | ·1 | ·1 | 10 | —36 | —36 | ·1 | 1 | 1 |
| 1 | 5 | 5 | 20 | —36 | —36 | 20 | —36 | —36 |
| ·1 | ·1 | ·1 | 20 | —36 | —36 | ·1 | 1 | 5 |
| 1 | 5 | 5 | 10 | —36 | —36 | 20 | —36 | —36 |
| 10 | 20 | 20 | 5 | 5 | 5 | 20 | 20 | 100 |
| 10 | 100 | 100 | 20 | —36 | —36 | ·1 | 1 | 1 |
| 1 | 10 | 10 | ·1 | 1 | 1 | 5 | 5 | 20 |
| 1 | 10 | 10 | ·01 | ·01 | ·01 | 5 | —36 | —36 |
|  |  |  |  |  |  | 10 | 10 | 10 |

### G. DETECTION OF THE BACILLUS ENTERITIDIS SPOROGENES, OR ITS CLOSE ALLIES

As these spore-bearing bacteria rarely occur in relatively large numbers in potable waters, the bacterial contents of a considerable volume is generally used for their detection.

River-waters and polluted waters contain these bacteria in greater abundance, hence comparatively small quantities of such waters need only be used for the examination.

Quantities varying from 1 c.c to 1 litre may require examination according to the character of the water. In from 1 c.c. to 100 c.c., or even 250 c.c., it is not necessary to concentrate the bacterial contents of the water, but for amounts exceeding 250 c.c. such concentration is convenient. The apparatus figured above answers admirably for the purpose.

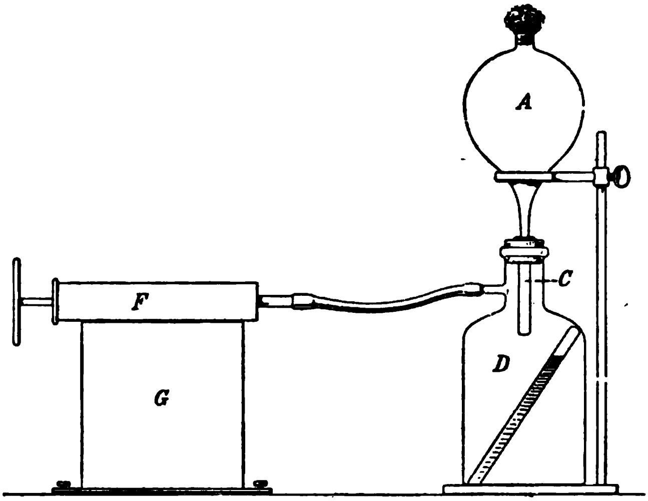


FIG. 16

*A* is a plain separating funnel of 500 c.c. or 1000 c.c. capacity drawn out at the lower end so that it can be tightly fitted by means of a small perforated rubber stopper into the porcelain filter tube *C*. This tube should hold about 50 c.c. of water when filled. *D* is the usual filter pump flask containing a piece of glass-tubing sealed at the upper end, and used for denoting the extent of the vacuum obtained by aid of the exhausting syringe, *F*, which is fixed securely to the bench on a block of wood, *G*.

The filter candle, *C*, is passed through a caoutchouc stopper, fitting tightly into the filter flask, *D*. The filter and flask, *A*, having been duly sterilised, half a litre of the water is poured into *A* and the neck lightly plugged with cotton wool. Upon exhausting the air from the flask by means of the syringe, filtration commences, and should be so regulated that about half a litre passes through in an hour. The filtration is stopped as soon as the water disappears from *A*, and the latter is then removed. The filtration is again proceeded with, until only 10 c.c. remain in the tube. The capacity of the tube being known, the filtering process can be easily stopped at very near this point. By means of a sterile brush, the organisms on the sides of the tube are brushed into the water and the whole or definite portions of the latter are transferred to tubes of recently boiled sterile milk, the temperature of which has been reduced to below 80° C. A little melted vaseline[1] is then poured over the surface of the milk in order to form a covering about ½ inch in depth. The tubes are next kept in a water-bath at 80° C. for fifteen minutes, then placed in cold water until the vaseline has set, and finally transferred to the incubator at 37° C., where they are kept for one, two, or three days. Before the expiration of the third day certain changes will have occurred in the milk if the spores of the Bacillus enteritidis sporogenes, or its near ally the Bacillus butyricus, are present. The casein will have separated in ragged clots, the upper portion having a more or less decided pink tint, the whey will be nearly transparent, and the vaseline plug will have been forced by the evolution of gas to the top of the tube. The gas evolved is inflammable, as can be ascertained by melting the plug whilst a light is held at the open mouth of the tube. The curdled milk has a strong odour of butyric acid, and is very acid to litmus. A drop of the whey examined under the $\frac{1}{12}$-inch objective will show large bacilli destitute of spores.

---

[1] A mixture of ordinary vaseline with a little paraffin wax, having a melting point of about 45°, forms the best plug. It can be sterilised occasionally by heating.

[illegible]

[illegible] water up to 150 c.c. can be [illegible] it is preferable to use, say, four flasks [illegible] the water to [illegible] the flask holding the [illegible].

[illegible] mixed with two volumes of the water [illegible] 250 c.c. flasks holding [illegible] and 125 c.c. of the milk [illegible] and sterilised. It is preferable to boil the milk in the flask [illegible] before use, and to pour in the water to be examined as soon as the milk has cooled slightly. The mixture of milk and water must fill the flask to a little above the base of the neck [illegible] for the expansion during heating and [illegible] the production of gas [illegible] by the pushing up of the vaseline plug.

A little skill is required to produce a good plug with the vaseline. The surface of the milk and water should be free from froth, and the melted vaseline should be run over the surface with a short pipette and as gently as possible. Test-tubes of sufficient capacity and containing 10 c.c. of sterile skimmed milk can be used for any quantity of water up to 20 c.c. For 50 c.c. and upwards, flasks with elongated necks are preferable. The usual quantities of water submitted for examination are 1 c.c. and 10 c.c. of crude river-waters, 10 c.c., 100 c.c., and 250 c.c. of purer waters. In special cases, several 250 c.c. quantities may have to be used, or the bacteria concentrated from one or more litres of water.

## H. Examination for Streptococci

At the present time, so little is known about the significance of the various groups into which streptococci can be differentiated by their action on sugars—glucose, lactose, mannite, dulcite, &c. —that in routine water examination it is a waste of time to do more than merely ascertain the presence or absence of these minute organisms, and to determine as approximately as possible their relative abundance. For this purpose many processes have been devised, but the simplest and best appears to be the microscopic examination of the bile-salt glucose broth used for the 'presumptive' test for Colon bacilli. The incubation should, however, be prolonged to forty-eight hours, and at the end of that period a loopful from the surface of each tube should be examined as a hanging drop under the microscope. The broth should then be carefully poured off, so as to leave at the bottom any precipitate which has been produced. Add a few drops of very dilute sodium carbonate solution to dissolve the bile-salts, and again examine in the hanging drop. If distinct chains of cocci are not found, streptococci may be regarded as absent.

Dr. Savage appears to prefer a neutral-red glucose broth to the bile-salt broth, but I certainly much prefer the latter.

The investigation may be carried further by spreading minute quantities of the broth after forty-eight hours' incubation over litmus lactose agar plates. After incubating for eighteen to twenty-four hours the minute colonies can be picked off and examined under the microscope to ascertain if any are due to streptococci. Houston has recommended bacterial concentrartion, as described under Section E, of 500 or 1000 c.c. of wateto 5 c.c. and 0·1 c.c. of the concentrate used for spreading over agar plates. At the end of twenty-four to forty-eight hours' incubation, the growths resembling those of streptococci are used for inoculating bouillon tubes: after twenty-four hours' growth at 37° C. hanging drops may be examined for the presence of chains of cocci. This is a tedious and troublesome process. The examination of the broth used for the 'presumptive' test for the Colon bacilli necessitates no special cultures and gives as valuable results as any other. In bile-salt glucose broth the Colon bacilli at first grow far more rapidly than the streptococci, but after eighteen to twenty-four hours the streptococci increase with greater vigour, and in forty-eight hours may be the predominant growth.

At present I examine all waters for Colon bacteria and for the Bacillus enteritidis sporogenes, and do not include a search for streptococci in routine work, save in exceptional cases; but I am not prepared to say that such a search is not desirable, especially in the case of waters of doubtful character, or where the most conclusive proof of dangerous contamination is required.

## I. Expression of the Results of the Bacteriological Examination

The following are examples of the results obtained by the methods recommended and of the way in which they may be recorded:

### 1. Water from a Deep Well in the Chalk. No known Source of Pollution

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| Bile-salt glucose broth . . . . . . | — | — | + | + |
| ,, ,, lactose agar . . . . . . | | | — | — |

Bacteria growing on gelatine, &c., in three days, 14.

(The growth was deep crimson rather than red in colour, and did not produce any haze in the medium. The organism proved to be allied to the B. prodigiosus, but I have not been able to identify it with any known bacillus.)

B. enteritidis sporogenes absent in 500 c.c.

*Report.*—The water is free from organisms of the coli type, and therefore is, in my opinion, free from dangerous sewage or manurial pollution.

### 2. Water from a Shallow Well in a Garden. Soil around heavily manured. Well Defective

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| Bile-salt glucose broth . . | + | + | + | + |
| „ „ lactose agar . . . . | + | | | |
| Litmus lactose broth . . . . | + + | (Acid & gas) | | |
| Motility . . . . . . | + | | | |
| Gram's stain . . . . | — | | | |
| Milk . . . . . . . | + + | (Acid & curd) | | |
| Peptone solution . . . | + | (Indol formed) | | |
| Neutral-red agar . . . | + | | | |
| Gelatine streak . . . . | — | | | |

Bacteria growing on gelatine, &c., in three days, 1980.

B. enteridis sporogenes present in 100 c.c.

*Report.*—This water contains Colon bacteria in 1 c.c. and the B. enteritidis in 100 c.c. (possibly in less). It is undoubtedly contaminated with sewage or manurial matter, and quite unfit for domestic purposes.

### 3. Water from a Well at a Mineral Water Factory. No known Source of Pollution near

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms capable of growing on gelatine in four days at 20° C . . . . . . | 1400 | | | |
| Bile-salt glucose broth . . . . . . | + | + | + | + |
| „ „ lactose agar . . . . . . | + | | | |
| Litmus lactose broth . . . . . . | + | | | |
| Motility . . . . . . . . | + | | | |
| Gram's stain . . . . . . . | — | | | |
| Milk . . . . . . . . . | — | — | — | — |
| Peptone solution . . . . . . | + | | | |
| Neutral-red agar . . . . . . | — | | | |
| Gelatine streak . . . . . . . | — | | | |

B. enteritidis sporogenes not found in 500 c.c.

*Report.*—This water contains a rather large number of bacteria and some of an objectionable type. It is bacteriologically unsatisfactory, and the well should be carefully examined.

As the result of this report the well was opened, and at a point near the ground surface-water was found trickling in. No doubt the organisms were derived from the soil of the surrounding pasture.

### 4. Water from the Mains of the East London Water Company

| — | 1. c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. . . . . . . | 180 | | | |
| Bile-salt glucose broth . . . . . . | + | + | + | + |
| ,, ,, lactose agar . . . . . . | — | — | — | — |

B. enteritidis sporogenes not found in 375 c.c.

*Report.*—Satisfactory. Contains no organisms suggestive of recent contamination by sewage or manure.

### 5. Water from the South Essex Water Company's Mains

| — | 1 c.c. | 5 c.c | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. . . . . . . | 178 | | | |
| Bile-salt glucose broth . . . . . . | — | + | + | + |
| ,, ,, lactose agar . . . . . . | | — | — | — |

B. enteritidis sporogenes not found in 500 c.c.

*Report.*—Satisfactory. No evidence of the presence of recent sewage or manurial pollution.

### 6. Spring Water from Plantation at —— Asylum

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. . . . . . | 9500 | | | |
| Bile-salt glucose broth . . . . . | + | + | + | + |
| ,, ,, lactose agar . . . . . . | + | | | |
| Litmus lactose broth . . . . . | + + | | | |
| Motility . . . . . . . . . | — | | | |
| Gram's stain . . . . . . . . | — | | | |
| Milk . . . . . . . . . . | + + | | | |
| Peptone solution . . . . . . | — | — | — | — |
| Neutral-red agar . . . . . | — | | | |
| Gelatine streak . . . . . . | — | | | |

B. enteritidis sporogenes.—After three days a little gas was produced and the milk was clotted, but the reaction was not at all characteristic of the B. enteritidis sporogenes.

*Report.*—This water appears to contain organisms of intestinal type, but there is no evidence of direct sewage pollution. It is far from satisfactory, and the source should be examined.

A week or two afterwards I examined the so-called spring, and found that water from swampy ground in a plantation collected in various rivulets, which ultimately combined to form the 'spring.' One of these rivulets received the water from a road drain near a public-house, where waggoners rested their horses. This was the only source of pollution discernible. Decaying leaves abounded in the streamlets. I sanctioned the use of the water for laundry and boiler purposes only.

### 7. Water derived from a Deep Well in the New Red Sandstone and supplied by a Large Water Company.

| — | 1 c.c. | 5 c.c. | 10 c.c. | 20 c.c. |
|---|---|---|---|---|
| No. of organisms, &c. . . . . . . | 78 | | | |
| Bile-salt glucose broth . . . . . . | — | + | — | — |
| „ „ lactose agar . . . . . . | | — | — | — |

B. enteritidis sporogenes not detected in 500 c.c.

*Report.*—The bacteriological examination affords no evidence of pollution.

## J. The Bacillus Typhosus

This organism is exceedingly difficult to detect in sewage-polluted waters; some assert that in the present state of our knowledge its isolation from such a water is impossible. The cases recorded in which it has been detected in water supplies are all open to doubt, since the characteristics given of the organism isolated would not now permit of the bacillus being definitely regarded as the true B. typhosus. In all fluid media as yet suggested, other organisms of intestinal type appear to grow more luxuriantly than the typhoid bacillus. I am constantly examining waters believed to have conveyed the infection of typhoid fever, but have never succeeded in satisfying myself that the specific organism was present. When a little broth containing the B. typhosus has been added to a good potable water, there has been little difficulty in detecting the organism for days afterwards, but if added in small amount to a sewage-polluted water I have invariably failed to isolate it later.

When present in relative abundance spread 0·1 c.c. over a plate of Drigalski and Conradi's medium, and after incubation pick off the blue or violet colonies and examine further. If not present in large numbers, the bacterial concentrate from 500 c.c. of the water may be used for making a series of plates.

In polluted waters the B. typhosus must be associated with a relatively large number of organisms belonging to the Coli groups, rendering its isolation difficult, save in the possible case of pollution with urine only.

Some have attempted bacterial concentration by filtration, by evaporating the water at a low temperature *in vacuo,* and by precipitating aluminic hydrate in the water and collecting the precipitate and entangled microbes, but there are grave objections to these methods. Houston prefers to concentrate the bacteria by centrifugalising 500 c.c. of the water to be examined and spreading the deposit over a series of sixteen plates of a special medium containing bile-salts, lactose, and other sugars, and neutral-red. After incubating at 37° C. for twenty-four hours, the colourless colonies (250 recommended) are subcultured in a peptone mannite litmus solution. After two days' incubation at 37° C., those showing no change are rejected, as also are those showing the production of gas. Those showing the production of acid only are further examined by inoculating a gelatine glucose litmus medium, incubating for three hours at 37° C., and then for twenty-three to thirty-five hours at 20–22° C. All showing gas productions are rejected, leaving a very limited number producing acid only for special study.

The following tests may then be applied:

(*a*) Inoculation of neutral-red broth. The typhoid bacillus produces a purplish tint. If gas or fluorescence is produced, the organism can be rejected.

(*b*) Peptone water-test for indol. The B.T. produces no indol.

(*c*) Peptone and various sugars solution tinted with litmus. The B.T. produces neither acid nor gas, nor any visible-change.

(*d*) Proskauer and Capaldi's No. 1 medium (modified). B.T. produces no change.

(*e*) Litmus milk medium. Slight acid change produced.

(*f*) Streak gelatine culture. The growth should have no tendency to liquefy the gelatine, but should be dry, translucent, and greyish yellow.

(*g*) Potato streak culture. The growth should be delicate, creamy, forming an almost invisible layer.

(*h*) Finally apply the agglutination test, using the antityphoid serum of an immunised animal. The growth used should be taken from an eighteen to twenty-four hours' culture on agar, and the reaction be observed with a serum dilution of, at least, 1 in 50. If a stronger serum is required to cause agglutination, the reaction has no value for diagnostic purposes.

Houston concludes that if one typhoid bacillus is present in 15 to 17 c.c. of water, it may be detected by his method.

For further details and formula for the special media, Dr. Houston's 'Fifth Research Report to the Metropolitan Water Board' should be consulted.

### K. The Bacillus choleræ asiaticæ

There is little difficulty in detecting this organism in water to which it has been added, provided the examination is not delayed more than two or three days, but it is very different when a sewage-polluted water is being examined, especially if the contamination has taken place several days before.

Various methods of examining water for the presence of the cholera vibrio have been described, the more important being those of Metschnikoff and Sanarelli. The vibrio, if present in a water, must be associated with the Bacillus coli communis and other organisms of the intestinal type; hence it would be useless searching for it if the latter organism were shown to be absent, or not relatively abundant. In the routine process of examination described in this work, the cholera bacillus, if present, would be contained in the growth in the bile-salt glucose broth associated with the organisms producing acid and gas, although the vibrio itself only produces acid in this medium. Upon the lactose agar medium the colonies would be white surrounded by a clear halo, since Hellin states that in contact with air in a lactose medium it produces alkali. Colonies could be selected and lactose litmus solutions inoculated therewith, and those rejected which showed gas production. The growth in the other tubes could be used for inoculating tubes of peptone solution. After incubation for twenty-four hours at 37° C. a little pure sulphuric acid should be added, and if a red colour is developed the examination may be carried further; but if no colour is produced, the tube fiom which the cultivation was made can be discarded. This so-called cholera-red reaction is by no means peculiar to the cholera vibrio. I have on several occasions obtained the reaction when testing for indol production in examining for the B. coli communis.

The red coloration being produced, and the organism when examined in the hanging drop showing a resemblance to the cholera vibrio, make—

(1) A gelatine plate or streak culture,
(2) A gelatine stab culture,
(3) An agar slope culture, and
(4) Inoculate a tube of litmus milk,

and compare the results with those obtained with the true cholera vibrio.

Koch says that the organism has no particular effect upon milk, but according to Hellin, as quoted by Lehmann and Neumann ('Bacteriology,' p. 359), 'in 10 c.c. of litmus milk the cholera vibrio forms a blue pellicle on the top, the following layer is red, the deepest part is decolorised (reduction); thus the formation of alkali is favoured by the entrance of oxygen, and the fermentation of sugar and formation of acid by anaërobiosis.' The agar growth should be tested with Pfeiffer's chlorea serum. A positive reaction with the serum diluted 100 times is said to be positive proof that the organism is the B. choleræ asiaticæ. If a stronger serum is required to produce the reaction, the evidence is inconclusive.

Metschnikoff and Sanarelli both employed strong peptone gelatine solutions which they added to certain quantities of the water to be examined. Sanarelli's medium contained potassium nitrate whilst Metschnikoff's did not. The former's solution contained 20 per cent. of gelatine, 10 per cent. of peptone, 10 per cent. of sodium chloride, and 1 per cent. of potassium nitrate. Quantities of water varying from 100 to 500 c.c. may be examined by adding one twenty-fifth the volume of the sterilised gelatine solution, and incubating the mixture at 37° C. for twelve hours. In the presence of the cholera organism a pellicle forms over the surface of the water within the time specified, and a loopful of this is transferred to a proper dilution of the gelatine medium with sterilised water and incubated for six hours only. From this a loopful is withdrawn and another similar solution inoculated. Finally, a little of this solution may be spread on agar plates, and the colonies resulting from the incubation examined for the production of cholera red. Those which give the reaction may be further examined as detailed on p. 517.

Houston, in his experiments with artificially infected Thames water, used 10 litres of water. To this he added 100 grammes of dry unsterilised peptone and 50 grammes of sodium chloride. The bottle was shaken and placed for about an hour in water kept at 37° C., and the contents then infected with a definite number of cholera vibrios. It was then placed in an incubator at 37° C., and after ten hours plate cultures were made on agar, bile-salt-agar, and Drigalski and Conradi's medium. Cholera vibrios having been previously grown on these media, their characteristics were known, and colonies resembling them were picked off the plates made from the infected water, and submitted to a series of tests for identification or rejection.

He concluded (Fourth Research Report) that the isolation of cholera vibrios from artificially infected raw river-water presents no insuperable difficulties, even when the number introduced is very small.

## L. OTHER SPECIAL EXAMINATIONS

Occasionally bacteriological examinations may be conducted for other purposes than the discovery of sewage pollution, as in the three following examples which have recently occurred in my practice :

(1) Two samples of water were submitted to me for examination. One (No. 1) was from a well about 30 feet deep, in a stable yard, supplying a mansion with water ; the other (No. 2) from a similar well which had been discovered in the basement, and which had evidently at one time supplied the house, as various pipes were connected with it. The second well was discovered when relaying the drains ; a drain was found near it, but it was in good condition. The soil around the well was removed and replaced by clean gravel and sand, and the well itself pumped dry and the sides thoroughly scoured. It was proposed to use this well water as the supply to the house, on account chiefly of its more convenient position.

The physical and chemical examination of the two waters gave the following results :

| Turbidity | No. 1. Quite Bright. No deposit | No. 2. Very dull. A little earthy deposit |
|---|---|---|
| Colour . . . . . . | Very faint yellow | Yellow tint |
| Odour . . . . . . | None | None |
| Chlorine . . . . . | 3·7 | 3·4 |
| Hardness . . . . . | 17·2 | 18·6 |
| Nitrites . . . . . | None | Trace |
| Nitric nitrogen . . . . | ·198 | ·20 |
| Free ammonia . . . . | ·003 | ·068 |
| Organic ammonia . . . . | ·006 | ·032 |
| Oxygen absorbed in 3 hours 98° F. | ·088 | ·200 |

The bacteriological examination showed that in 5 c.c. of each, there were organisms present capable of fermenting glucose in the presence of bile-salt. The contents of these broth tubes were used for making dilutions with which MacConkey's agar neutral-red medium was smeared.

No. 1 gave red colonies in twenty-four hours, and some of these gave all the reaction of the Colon bacilli, except the formation of indol.

No. 2 gave after forty-eight hours a number of minute colourless colonies, not at all resembling those of the Coli groups.

The filter brushings from 350 c.c. of No. 1 gave, with milk, the characteristic reaction of the presence of the B. enteritidis sporogenes of Klein.

The filter brushings from 350 c.c. of No. 2 gave no such reaction.

There could be no doubt therefore that No. 1, notwithstanding its considerable organic purity, contained organisms indicative of sewage or manurial pollution, though possibly not of recent character. The chemical results obtained with No. 2 strongly indicated sewage pollution, but this I was assured was impossible. The bacteriological results also tended to negative the assumption that the organic matter was due to sewage. A further bacteriological examination was therefore made.

A tube of bouillon to which a little potassium nitrate had been added was inoculated from the fermenting glucose broth and kept at 37° C. for twenty-four hours. It was then tested for nitrites, and found to contain so large a quantity that when one or two drops were added to 50 c.c. of water, the test for nitrite with starch, iodide, and acid, gave a most marked and instant reaction. The same result was produced when a nitrated broth was infected with a little of the original water.

A litre of good tap water containing about 1 part of nitric nitrogen per 100,000 was infected with 1 c.c. of the water, and to a second litre, similarly infected, were added 5 c.c. of bouillon, and 250 c.c. of each were examined on four successive days.

The water containing no added organic matter remained practically unchanged, whilst nitrites and ammonia developed rapidly in the one containing the broth. Obviously, therefore, this sample contained an organism capable of rapidly reducing nitrates to nitrites and ammonia in the presence of organic matter, thus accounting for the presence of these substances in the water.

Although this water was almost certainly free from sewage pollution, I could not approve of its use for domestic purposes whilst in this condition.

(2). In this case a well-water showed signs of turbidity, and deposited a little red flocculent matter, giving it an unsightly appearance. The cause of this was to be investigated. The water was satisfactory bacteriologically, showing no signs of sewage pollution, and the report on the well showed that any such pollution was practically impossible. The chemical analysis showed the presence of a trace of iron, nitrites were absent, and it contained practically no free ammonia. The organic ammonia, 0·054 part per 100,000 of water, proved that the water contained a considerable amount of organic matter.

The microscopical examination showed the presence of myriads of micrococci or spores and many filaments, suggestive of crenothrix. A portion of the water containing some of the red deposit was centrifugalised. The clear water was then poured off and the residue mixed with more sterile water and again centrifugalised. This process was repeated several times. A little of the washed deposit was then spread on sterilised potato, which had been moistened with an exceedingly dilute solution of ferric chloride. In a few days the whole surface of the potato was covered with a wrinkled reddish growth, which later became chocolate-coloured. Under the microscope this consisted of a mass of spores and hyphæ. A trace was added to a little water containing ferrous carbonate and incubated. A flocculent growth occurred within a few days, resembling in all respects that found originally in the water.

There was no doubt the water, containing organic matter and a trace of iron, had become infected with a crenothrix, and to this the unsightly appearance was due.

(3). In this case I had to examine a water with a decided odour of sulphuretted hydrogen, derived from a source apparently free from the possibility of sewage pollution, and upon chemical and bacteriological examination the water gave no indications of such contamination.

Two c.c. were added to a tube of gelatine, containing a small quantity of solution of tartrated iron and incubated at 20° C. After several days the gelatine blackened from below upwards, indicating the presence of some organism capable of producing sulphuretted hydrogen. The bacillus isolated appeared to be the bacillus fluorescens.

On page 522 is shown the form which I am at present using for bacteriological reports, filled in with the results of the recent examination of a few samples of water:

No. 1 was from a well 300 feet deep, sunk through the London clay. Water raised by an air-lift pump. Sample carefully taken from an outlet from the pump, and examination commenced within a few hours. There is no possibility of pollution. Water reported satisfactory, as the chemical analysis showed that it was of the highest degree of organic purity.

No. 2, superficial chalk-well supplying a large town. Reported quite satisfactory.

No. 3, gravel spring-water supplying a population of 5000. Taken after continued heavy rain. Reported of excellent quality.

No. 4, a deep well in Central Essex. Contained Colon bacilli. No possibility of pollution. The chemical analysis giving excellent results, the water was passed as satisfactory.

Nos. 5 and 6 were from two deep borings in the new red sandstone in Cheshire. Both waters were of the highest degree of organic purity, yielding no albuminoid ammonia, and practically absorbing no oxygen from potassium permanganate, yet No. 6 contained B. coli in 60 c.c. Both were passed as perfectly satisfactory, but the manager of the works was asked to examine the receiving tank, as on a previous occasion, when B. coli was found, the tank was found to have been affected by dust and dirt from the room above.

No. 7, a deep well in Essex sunk through 300 feet of London clay to the sands beneath. Water raised by an air-lift pump.

REPORT ON THE BACTERIOLOGICAL EXAMINATION OF A SAMPLE OF WATER

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of organisms per cubic centimetre capable of growing upon nutrient gelatine at 20° C. in three days . . . . | 2500 | 26 | Liquefied | 60 | 18 | 67 | 2500 | Liquefied | 710 | abt. 6000 | 786 |
| Number of organisms per cubic centimetre capable of growing upon agar at 37° C. in one day . | 47 | 0 | 0 | 5 | 0 | 6 | 47 | 30 | 5 | overgrown with B. mycoides | |
| Smallest quantity of water-giving acid and gas in bile-salt glucose broth . . . . . . . | 1 c.c. | —36 c.c. | —100c.c. | 5 c.c. | —100c.c. | 60 c.c. | 1 c.c. | 20 c.c. | —36 c.c. | —36 c.c. | 5 c.c. |
| Smallest quantity of water giving gas in bile-salt lactose broth . | 5 c.c. | —36 c.c. | —100c.c. | 20 c.c. | —100c.c. | 60 c.c. | 5 c.c. | 20 c.c. | —36 c.c. | —36 c.c. | 5 c.c. |
| Smallest quantity of water containing the Bacillus coli communis . | —36 c.c. | —36 c.c. | —100c.c. | 20 c.c. | —100c.c. | 60 c.c. | 5 c.c. | 20 c.c. | —36 c.c. | —36 c.c. | 5 c.c. |
| Smallest quantity of water giving the reaction of the Bacillus enteritidis sporogenes . . | —150c.c. | —150c.c. | —100c.c. | —200c.c. | —110c.c. | —110c.c. | —110c.c. | —100c.c. | —150c.c. | —150 c.c. | + 150 c.c. |

The water is frequently examined and is always of the highest chemical purity, yet it frequently, but not invariably, contains the B. coli and a large number of bacteria. I regard the water as perfectly safe.

No. 8, water from a public supply, direct from the mains. The results appeared unsatisfactory, and samples taken from other mains near gave far better results. Another sample was taken from the same tap, which was found to be very slimy inside. On this occasion the tap was sterilised before taking the sample.

No. 9, the water above referred to taken from the sterilised tap.

No. 10, water from a well supplying a mansion. Pumped into a large, open tank, which then supplied the house.

No. 11, water drawn from the tank in which No. 10 was stored. The well was not properly constructed, but there was no source of dangerous pollution near. During storage the number of bacteria appeared to have decreased, but objectionable organisms had made their appearance. The waters were unsatisfactory, and their owner was advised (1) to have the well reconstructed, and (2) to have the cistern thoroughly cleaned and properly covered.

From time to time the question arises, whether a water is fit for use in a swimming bath, or whether a river-water is sufficiently pure to be used to supply a bath, or whether an Authority is justified in permitting persons to bathe in a river. These are exceedingly difficult questions to answer, and I have not found that bacteriological examinations give much assistance. Persons may bathe with apparent impunity in waters utterly unfit for drinking purposes, yet I have known many outbreaks ot enteric fever attributable to bathing in sewage-polluted streams. Very guarded opinions should be given in every case unless, the water is of considerable chemical purity. On three occasions during the past summer, my opinion has been asked on some doubtful waters, and the results of the analyses on p. 524, and copies of the reports thereon, may be of interest.

| | 1<br>River-water | 2<br>Bath-water | 3<br>Bath-water |
|---|---|---|---|
| Appearance . . . . . | Faint yellow, clear, little veg. debris | Dull. No deposit | Dull. No deposit shows |
| Chlorine, per 100,000 . . . | 2·6 | 3·9 | 5·3 |
| Nitrites ,, ,, . . . | Nil | Nil | Large trace |
| Nitric nitrogen . . . | 0·36 | 0·20 | 0·30 |
| Free ammonia . . . | 0·110 | 0·022 | 0·100 |
| Organic ammonia . . . | 0·022 | 0·023 | 0·117 |
| Oxygen absorbed . . . | 0·40 | 0·108 | 0·284 |
| Bacteriological results . . | B. coli present in 5 c.c.<br>B.e.s. present in 100 c.c.<br>No streptococci | All kinds of sewage bacteria present. | |

*Report on No.* 1.—Knowing that no serious contamination affects this stream for some distance above the proposed intake, and that the water is to be filtered through sand before entering the bath, I think it may be used for the purpose. Water should not be taken from the river after very heavy rains, as dangerous polluting matter may then enter the river from the field and other ditches.

*Report on No.* 2.—(From a public bath which had been in use some days, and which is filled from the public water supply.) This water shows unmistakable signs of pollution, and I think the limit of permissible impurity has been reached.

*Report on No.* 3.—This water is so very much more impure than the water used for filling the bath, that I think the limit of permissible impurity has been exceeded.

# CHAPTER XX

## THE MICROSCOPICAL AND BIOLOGICAL EXAMINATION OF A POTABLE WATER

The examination of the sample of the water in the long tube to ascertain its colour will almost certainly have shown whether it contained any suspended matter. Sometimes, however, the visible particles are so few that they can only be discovered by examining the water in bulk by bright transmitted light. This is a simple matter if the sample is contained in a large bottle of colourless or but slightly coloured glass. If the water has been delivered in a bottle of dark glass or of earthenware, it is desirable to transfer it to a white glass bottle for the purpose of examination. The following incident will show the importance of this procedure. A few years ago I examined a sample of deep well-water and found in it a few algal filaments. I expressed the opinion that some surface-water was trickling into the well; or that there was some defect in the service reservoir. A sample was sent to another analyst, who reported that the water was free from any vegetable growth. Chemically the water was of excellent quality. A little later the water became visibly affected by this algoid growth, which was found to be due to an imperfection in the roof of the reservoir allowing light to gain access. Soon afterwards I received a letter from the other analyst saying that by accident the dark glass bottle which had contained the sample submitted to him had been broken, and that on examining it he had found the sides covered with a green confervoid growth.

A minute deposit may often be discovered by carefully examining the bottom of the containing vessel after it has stood at rest for a time. *As a matter of routine any deposit of this kind should be examined microscopically.* Occasionally also a chemical or micro-chemical examination is indicated, as, for example, when the deposit resembles ferric hydrate.

In these cases the deposit may appear to be dissolved upon the addition of a little dilute acid, but such deposits, especially if flocculent in character, are very often associated with fungoid growths, and the latter may easily be overlooked if not carefully sought for.

As a rule, it suffices to fill a conical test-glass with the water and set it aside for twenty-four hours, when the larger organisms and other matters in suspension will settle upon the sides and bottom of the glass. By carefully siphoning off the supernatant clear liquid, the suspended matter is concentrated into a very small volume of water, and droplets can be removed for examination under a low power of the microscope. For this purpose, hollow-ground slides are very useful. When it is desired to preserve such deposits for future examination, they can be preserved in a solution of cupric chloride, &c., in camphor water (*vide* Formulæ). To collect the organisms from water passing through mains, a small bag of fine linen may be tied over the mouth of a tap, which is then left running for a period. When the bag is removed it is turned inside out and gently immersed in a small quantity of water to remove all the organisms, or a piece of fine linen may be tied over the small end of a funnel and a quantity of water passed through. The linen is then removed, and by blowing through it the deposit can be received upon a slide and examined, or the deposit may be collected on small sheets of hardened and well-washed filter paper placed in a suitable funnel.

By aid of a wash-bottle containing filtered water, the deposit on the filter paper is washed into a small tube drawn out to a point at the end, and the tube introduced into a hand centrifuge. The deposit is thus obtained at the point of the tube, and an idea can be formed of its quantity; it can then be transferred to a slide for examination under the microscope.

Mr. Dibdin prefers to use a method of collecting the deposit formed on sides of the filter paper, which admits of the amount of sediment being expressed numerically. He draws out the end of a piece of combustion tubing until the capillary portion has an internal diameter of 2 mm. The end of this is plugged with a paste of clay and kieselguhr, and heated to redness to 'set' the mixture. The filter deposit is washed into this tube, and filtered out by the kieselguhr plug, the process being accelerated by the use of the filter pump. When only a drop of the water remains in the micro-filter the length of the deposit can be measured. The end of the capillary tube can be cut off, and the deposit blown out upon a slide for examination.

In any process of filtration the filter paper must be previously rinsed with filtered water, and be kept covered while the water is passing through. With very clear waters a litre or more may be required to furnish any visible deposit, but 250 to 500 c.c. suffice with most waters submitted to examination.

There is a difficulty sometimes in removing the deposited matter for examination, without damaging many of the organisms so as to render their recognition impossible. This is obviated by the quantitative and qualitative method known as the Sedgwick-Rafter method. The following description is taken from Rafter's little work on 'The Microscopical Examination of Potable Water.'

'The bottom of a funnel is plugged with wire cloth, and upon this is placed about half an inch of clean coarse sand. This is lightly pressed with a glass rod, and from 20 to 40 c.c. of freshly filtered water allowed to run through to ensure the settling of the sand. The amount of water to be filtered is gauged by the number of organisms which it contains, as ascertained by a preliminary inspection. Generally, however, as large a quantity should be used as can be conveniently filtered without clogging the sand so much as to render the completion of the process too prolonged. For all ordinary purposes, 500 c.c suffice. The first 100 or 150 c.c. passed through are returned to the funnel. After all the water has passed through, the wire cloth is removed, and the sand and contained organisms washed with 5 c.c. of freshly filtered water, run from a 5 c.c. pipette into a 5 or 6 inch test-tube. The test-tube is slightly shaken to wash all the organisms clear from the sand, the latter from its greater specific gravity sinking quickly to the bottom, leaving the organisms distributed through the water. At the instant of the completion of the settling of the sand, the supernatant water is turned into another smaller test-tube, leaving the clean sand at the bottom of the first tube. The organisms from 500 c.c. of water are now concentrated in 5 c.c. After slight stirring to secure uniform distribution, 1 c.c. is transferred by means of a pipette to a specially prepared cell of 50 × 20 mm. area and of exactly 1 mm. in depth. Such a cell, of course, just holds 1000 cubic mm. or 1 c.c. The top of the cell (preferably the sides should be constructed of metal) is ground perfectly smooth, and a cover-glass, thoroughly cleaned and moistened, is placed over it by sliding gently from one end. With a little practice, this can be done without enclosing any air-bubbles or losing a drop of the liquid.

'For the purpose of enumeration, an eye-piece micrometer is required, so ruled as to cover, with a given objective and fixed tube length, a square millimetre on the stage. The mechanical stage recommended has a precise millimetre movement, so that the position of the squares counted is definitely known. This movement is insisted upon as an integral part of the method. Rafter recommends that about 50 squares should be counted. The working objective for these counts may be either a two-thirds or a one-half inch. In certain cases for identification purposes, a higher power may be required.

'The amorphous organic matter is estimated "mentally," a unit of area being 20 square microns.'

The Table on page 529 shows how the results are tabulated.

An expert biologist who has made a special study of organisms found in water may venture to name most of those found in potable waters, but it is impossible, even for an expert, to recognise all the forms. There is no doubt that many freshwater algæ, for

NUMBER OF ORGANISMS PER C.C.

| Source of sample | Spring | Lake waters of medium quality | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Sponge spicules . . . . . . | 0 | 0 | 1 | 1 |
| Rhizopods . . . . . . . | 1 | 0 | 1 | 0 |
| Infusoria . . . . . . . | 0 | 21 | 50 | 16 |
| Rotifera . . . . . . . | 0 | 3 | 6 | 1 |
| Crustacea . . . . . . . | 0 | 0 | 1 | 0 |
| Total animals . . . . . | 1 | 24 | 59 | 18 |
| Desmidieæ . . . . . . . | 0 | 3 | 4 | 5 |
| Diatomaceæ . . . . . . | 8 | 19 | 45 | 50 |
| Zoospores . . . . . . . | 26 | 244 | 88 | 2400 |
| Chlorophyceæ . . . . . . | 0 | 55 | 13 | 1 |
| Cyanophyceæ . . . . . . | 0 | 157 | 110 | 0 |
| Fungi . . . . . . . | 0 | 0 | 0 | 0 |
| Total plants . . . . . | 34 | 478 | 260 | 2456 |
| Amorphous matter . . . . . | 165 | 238 | 230 | 45 |

example, exhibit very different forms during their life-histories; and many forms now bearing distinct names are really the same organism at different stages of its existence.

Those who wish to make a special study of these low forms of vegetable and animal life must consult the most exhaustive treatises on this class of organism. The best probably are :

Cooke's ' British Freshwater Algæ, exclusive of the Desmidieæ and Diatomaceæ.'

Cooke's ' British Desmids.'

Smith's ' Synopsis of the British Diatomaceæ.'

De Barry's ' Comparative Morphology and Biology of the Fungi Mycetozoa and Bacteria.'

Baird's ' Natural History of the British Entomostraca.'

Hudson and Gosse's ' The Rotifera.'

Allman's ' Freshwater Polyzoa.'

Kent's ' Manual of the Infusoria.'

Whipple's ' The Microscopy of Drinking Water.'

The best single work covering the whole ground is undoubtedly the ' Anleitung zur Untersuchung des Wassers, mit besonderer

Berücksichtigung von Trink- und Abwasser,' by Dr. C. Mez, Professor at the University of Breslau.

The objects seen under the microscope can be divided into five groups :

1. Mineral matter.
2. Dead vegetable matter.
3. Dead animal matter.
4. Living vegetable organisms.
5. Living animal organisms.

The mineral matter, as a rule, admits of easy identification.

If the presence of chalk is suspected, a little dilute hydrochloric acid may be run under the cover-slip, when the particles of chalk will be seen to dissolve, giving off bubbles of gas. If oxide of iron is present, a droplet of solution of potassium ferrocyanide may be passed under the cover-slip after the acid, when the presence of iron will be revealed by the production of a blue colour. Particles of clay and sand will be unaffected by these tests.

Dead vegetable matter is often difficult to recognise, but usually some cell or fibre will have escaped complete disintegration and thus aid in its identification. Dead animal matter is, as a rule, more readily recognised, as destruction by maceration is rarely so complete as to obscure the origin of the débris.

The differentiation of animals from plants is frequently exceedingly difficult, if not impossible, in the lower forms of life. The presence or absence of organs of locomotion is not always reliable for the differentiation, as many algæ in certain stages of their existence possess flagella ; whilst other organisms, which on physiological grounds must be classed as animals, either are motionless or require prolonged observation to detect their motility.

Search should be made for the animal and vegetable growths, the presence of which has special significance. The more important of these are described in Chapter IX, and are illustrated on one or more of the plates in this section.

A careful study of the following illustrations of deposits found in waters from various sources will, when taken in connection with the descriptions of the sources from which they were derived, suffice for most practical purposes to enable an observer to draw reliable conclusions as to the source of the suspended matter found in a water, and this is the utmost which can be attempted by anyone who has not made a prolonged and systematic study of the lower forms of animal and vegetable life.

# PLATES

## PLATE I

The forms shown on this plate were contained in a sample of water from a stream on Dartmoor which was used in its unfiltered condition for the supply of a small town. After heavy rains the town supply contained visible particles, sufficient in number to cause complaints to be received from the consumers. The nature and the source of the deposit found in the water were submitted to me for investigation. I examined a sample of the water from the stream feeding the reservoir supplying the town, and afterwards the water which came from the mains during a period of heavy rainfall.

The deposit from the brook water contained a number of organisms, vegetable débris, &c., characteristic of water from such sources.

1. Vegetable débris—remains of cells, fragments of diatoms.
2. Staurospermum viride. F.W.A.[1] N.O. Zygophyceæ.
3. Lemanea torulosa. F.W.A. N.O. Lemaneaceæ.
4. Desmid. F.W.A. Species of Penium.
5. Pleurococcus. F.W.A. N.O. Palmellaceæ.
6. Dead form of 3. Cells plasmolysed.
7. Ulothrix tenuis. F.W.A. N.O. Ulotricheæ.

8-12. Various forms of algal filaments. 9 is evidently a species of Ulothrix. 10 was motile.

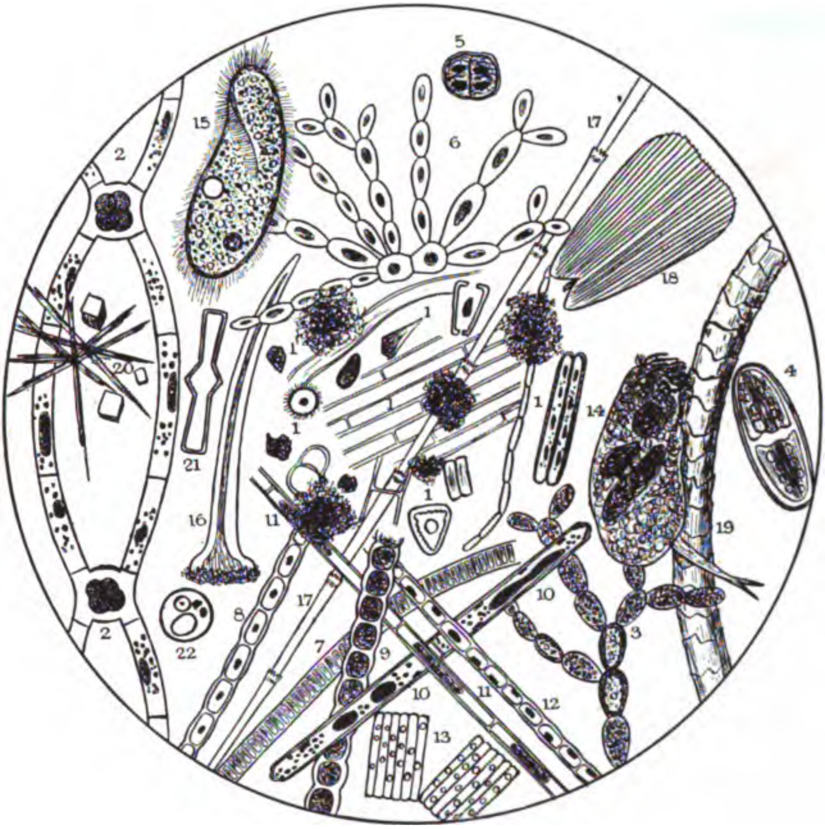
13. Diatom. F.W.A. Sub-family Fragilarieæ.
14. A rotifer or wheel animalcule. Animal of sub-kingdom Annuloida.
15. Paramœcium (Nassula ?). S.K. Protozoa. Class Infusoria.
16. An animal spine.
17. Hair of insect.
18. Wing scale of insect.
19. Fibre of wool.
20. Crystal; probably calcium sulphate.
21. Skeleton of a diatom.
22. Not identified. Free swimming, but no visible cilia.

All magnified 300 diameters.

---

[1] F.W.A. = Freshwater Algæ

## PLATE I



## PLATE II

The first twenty organisms on this plate were found in the water from the mains supplied by the reservoir referred to in Plate I. It is obvious that water from such a source should not be supplied without prior filtration. There are no organisms indicating sewage or manurial pollution.

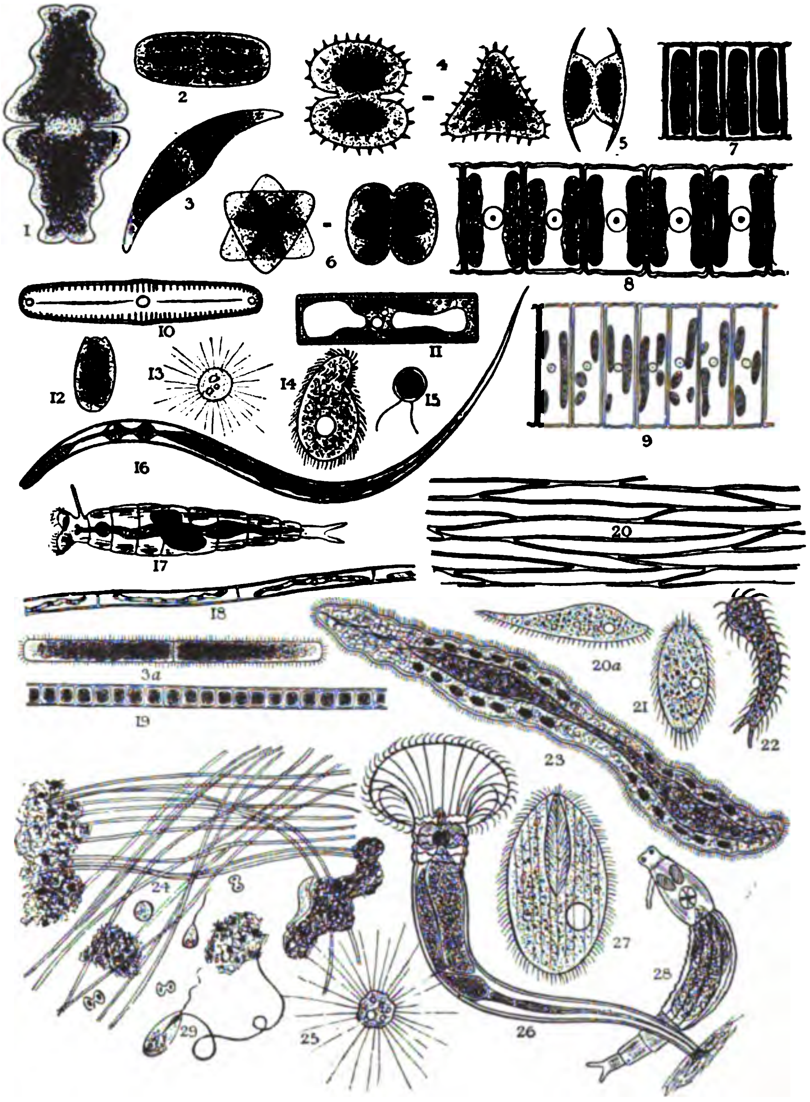
1-6. Various kinds of desmids:
  1. Euastrum pinnatum.
  2. Penium Brébissonii.
  3. Closterium Leibleini.
  3*a*. Docidium hirsutum.
  4 & 6. Species of Staurastrum.
  5. Arthrodesmus convergens.
7-11. Various kinds of diatoms:
  7, 8, & 9. Species of Fragilaria.
  10. Dead Pinnularia.
  11. A Pinnularia (?).
12. An infusorian in resting stage.
13. Actinophrys Sol. S.K. Protozoa. Class Rhizopoda.
14. A species of Paramœcium. S.K. Protozoa. Class Infusoria.
15. An algal zoospore.
16. Species of Anguillula. A nematode worm.
17. A rotifer.
18. Species of Mesocarpus. F.W.A.
19. Species of Ulothrix. F.W.A.
20. Vegetable tissue.

Figs. 20*a* to 29 are from another moorland water supply. All were found in a sample taken from the town mains (N. Wales).

20*a*, 21, 22. Ciliated animalcula.
23. Probably a spirostomum. N.O. Ciliata.
24. Crenothrix. (*Vide* Plate XVIII., Nos. 7*a*, 7*b*.) Fungus allied to Sphærotilus and Beggiatoa.
25. Actinophrys Sol.
26. A rotifer (Œcistes).
27. Large infusorian.
28. Rotifer with cilia withdrawn.
29. A small infusorian with long cilium, attached like a vorticella.

All magnified 300 diameters.

# PLATE II



1
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3a
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20a
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26

## PLATE III

At a later date the water referred to in the description of Plate II., Nos. 20*a*–29, became quite green in appearance, and acquired, when warmed, a disagreeable odour. The water was found to be swarming with a pleurococcus, and to the death and decay of this organism I attributed the odour observed.

1. A desmid (Arthrodesmus).
2. Scale from wing of moth or butterfly.
3. A desmid (Ankistrodesmus).
4. Hair of insect.
5. Minute protozoon.
6. A ciliate infusorian.
7. An amœba.
8. As fig. 3.

9 & 11. Diatoms.

10. A small desmid.

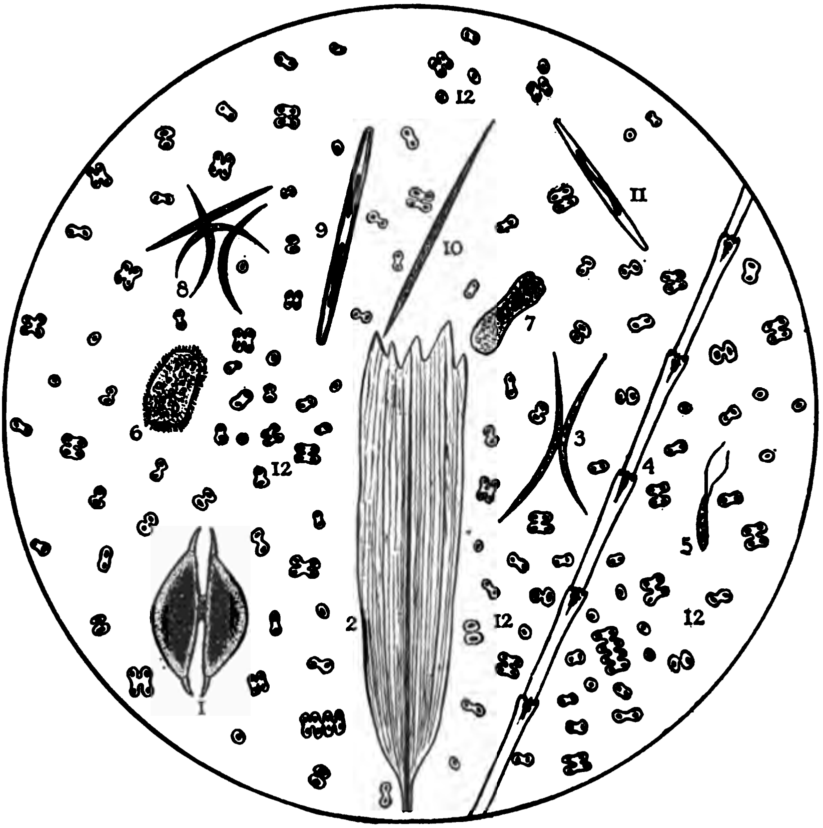
12. Pleurococcus. The members of this genus of the order Palmellaceæ are very frequently met with in waters.

The description of the genus given by Cooke is : ‘ Cells gregarious, globose, or angular ; single or associated in small families. Cell-contents green, or oily red. Multiplication by division in alternate directions. Propagation by gonidia.’

This water formed a green deposit in any jug or vessel in which it was left, and in glass vessels exposed to light the pleurococcus grew luxuriantly.

All magnified 300 diameters.

# PLATE III



## PLATE IV

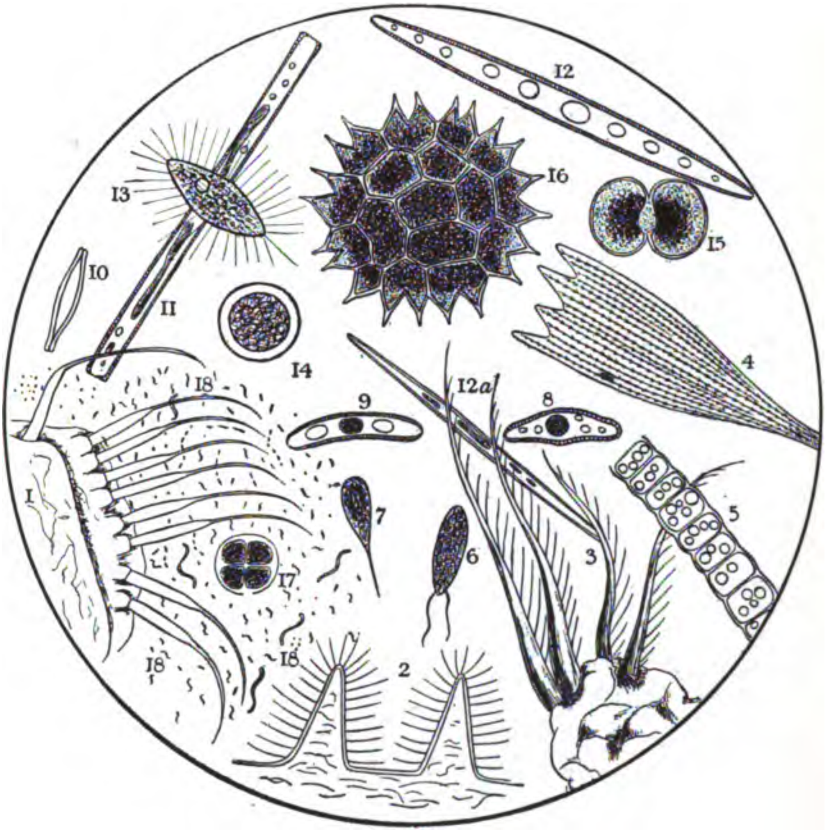
### DEPOSIT FOUND IN A WATER RESERVOIR

The organisms &c. shown in this plate were found in water from an uncovered service reservoir. Complaints had been received of 'insects' being found in the water drawn from the house taps. Upon examining the service reservoir an accumulation of débris was found in it. I advised that it should be covered and ventilated in such a way as to prevént access of light.

1, 2, 3. Fragments of animal tissue.
4. Scale from wing of moth or butterfly.
5. Dead algal filament.
6 & 7. Ciliated monads. S.K. Protozoa. Class Infusoria.
8–12*a*. Various diatoms.
13. A very active infusorian; probably Halteria.
14. An encysted form of infusorian.
15. Cosmarium (a desmid).
16. Pediastrum (discoidal desmid).
17. Pleurococcus undergoing division.
18. Various bacteria (spirilla, bacilli, and micrococci).

1-4 magnified about 50 diameters.
5–18 magnified about 300 diameters.

# PLATE IV



## PLATE V

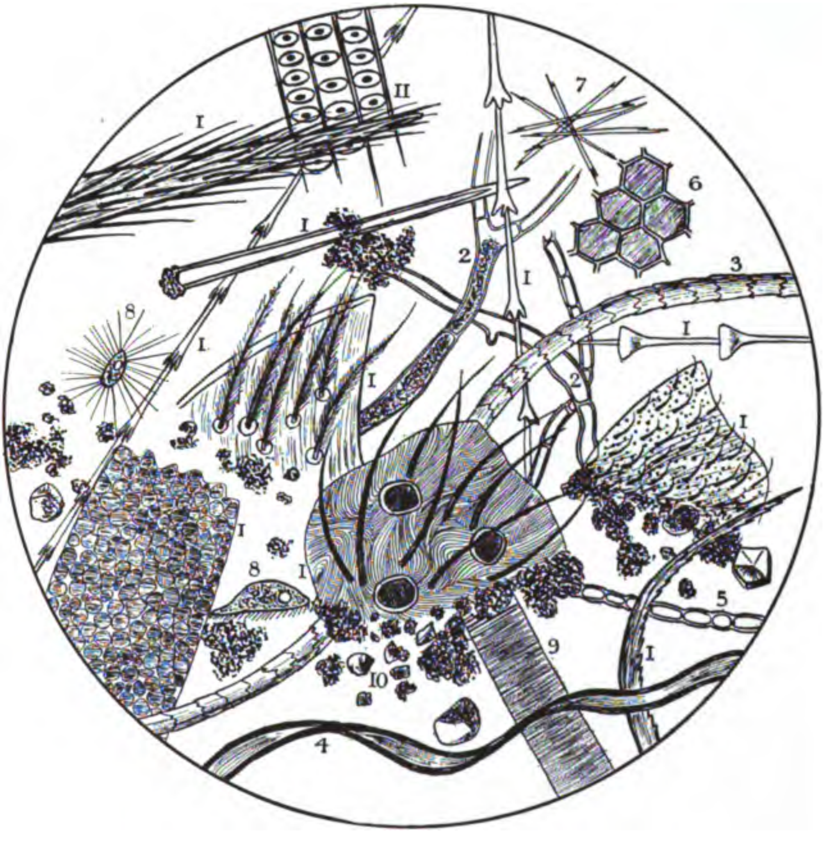
### SAMPLE OF WATER FROM AN UNCOVERED HOUSE CISTERN

Many cases of typhoid fever having occurred in a group of houses near a sewage works and dust shoot, the houses were examined and found to have small uncovered cisterns in the sculleries. The water from one of these cisterns was sent to me for bacteriological examination. The deposit in it, when examined microscopically, was found to contain remains of insect life. Quite possibly many of these insects had been hatched in the refuse heaps. Bacteriologically the water was very foul, and contained the B. coli in fair abundance.

1. Hairs, appendages, and wing-cases of various animals.
2. Fungal hyphæ.
3. Wool fibre.
4. Cotton fibre.
5. Dead algal filaments.
6. Portion of eye of insect.
7. Crystals of calcium sulphate.
8. A ciliate animalcule.
9. Probably the trachea of an insect.
10. Sand and mineral débris.
11. Wood of Conifer.

1 & 10 magnified about 50 diameters.
2-9 highly magnified.

## PLATE V



## PLATE VI

### WATER FROM RIVER BELOW A SMALL DYE-WORKS

This river water was not obviously polluted, though complaints were occasionally made of unpleasant smells arising in the vicinity, and attributed to the effluent from the dye works. This effluent had been treated chemically and contained a trace of iron. Crenothrix was found to be flourishing in the water. It occurs chiefly in water containing a little organic matter in solution together with a trace of iron.

1. Crenothrix polyspora. Tuft attached to dead leaf.

1*a*. Crenothrix polyspora. Portion of this fungus more highly magnified, showing spore formation. *Vide* Plate XVIII.

2. Probably an artodiscus without contractile vacuole. S.K. Protozoa Class Rhizopoda.

3. An amœba.

4, 4*a*, 4*b*, 4*c*. Various diatoms.

5. Algal filament (Ulothrix). Cells in act of dividing.

6. Spiral vessel of flowering plant.

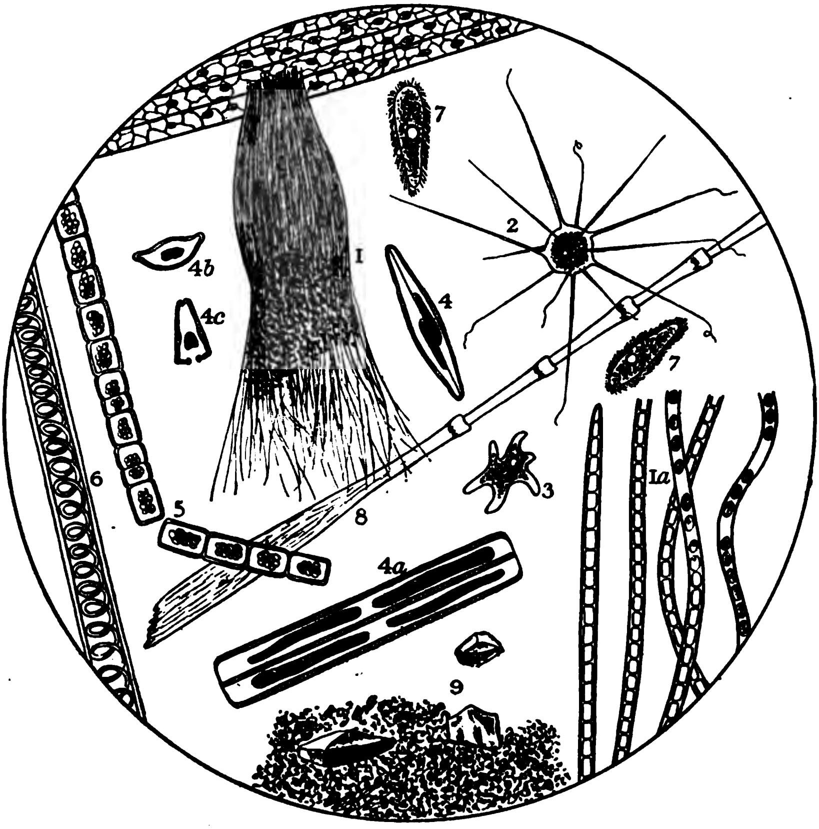
7. Small paramæcium.

8. Hair of insect.

9. Particles of sand embedded in vegetable débris.

No. 1 magnified 20 diameters, 1*a* about 500 diameters,
the others about 250 diameters.

## PLATE VI



## PLATE VII

### A SEWAGE EFFLUENT FLOWING INTO AND POLLUTING A RIVER

May be taken as typical of a grossly polluted water. The sewage had merely flowed over a small area of land, and had undergone no process of treatment or filtration.

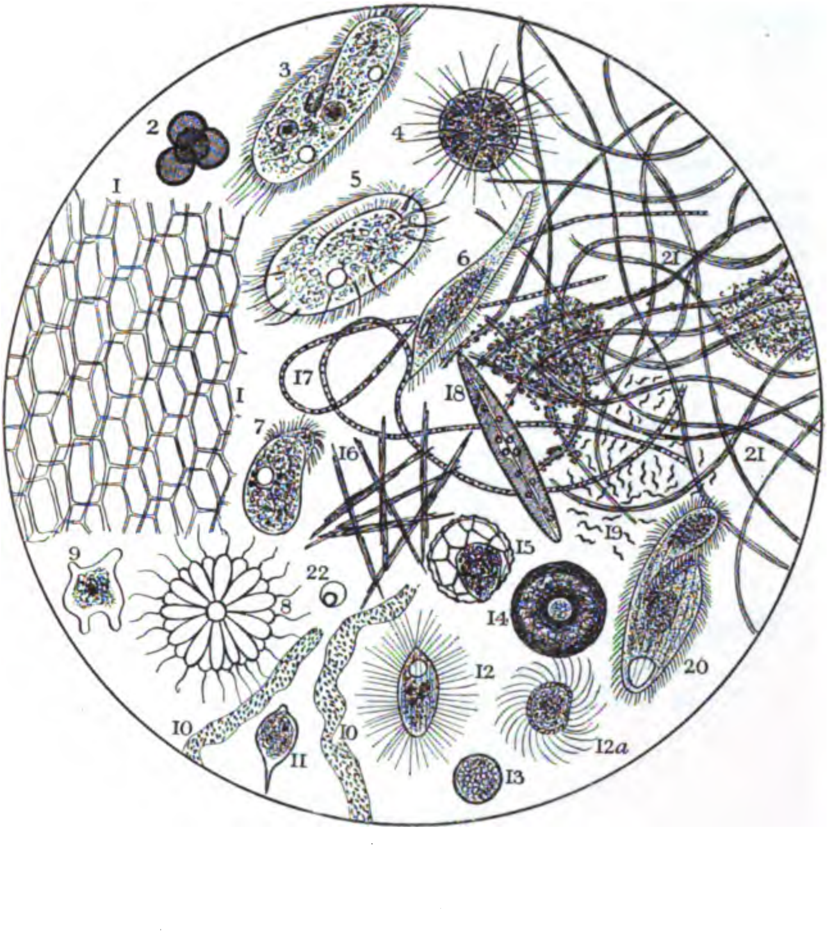
1. Pith cells of a flowering plant.
2. Tetrahedral spores ?
3. Species of Stylonychia. A ciliate infusorian.
4. One of the Heliozoa. S.K. Protozoa. Class Rhizopoda.
5. Euplotes vannus. An infusorian.
6. Oxytricha gibba. An infusorian.
7. A ciliate infusorian.
8. Synura uvella. A confervoid alga.
9. A lobose amœba.
10. Gelatinous mass of bacteria.
11. Euglena viridis. A ciliate infusorian.
12. A very active infusorian (Halteria ?).

12*a*. The same at rest.

13. Egg of an entozoon.
14. Arcella. S.K. Protozoa. Class Rhizopoda.
15. Probably an encysted form of some protozoon.
16. Crystals of calcium sulphate.
17. Beggiatoa alba.
18. Diatom (Navicula).
19. Spirilla.
20. Leucophrys spathula (ciliated infusorian).
21. Mass of fungal hyphæ with vegetable débris.
22. ? Motile, with highly refractive spot.

Magnified about 300 diameters.

# PLATE VII



## PLATE VIII

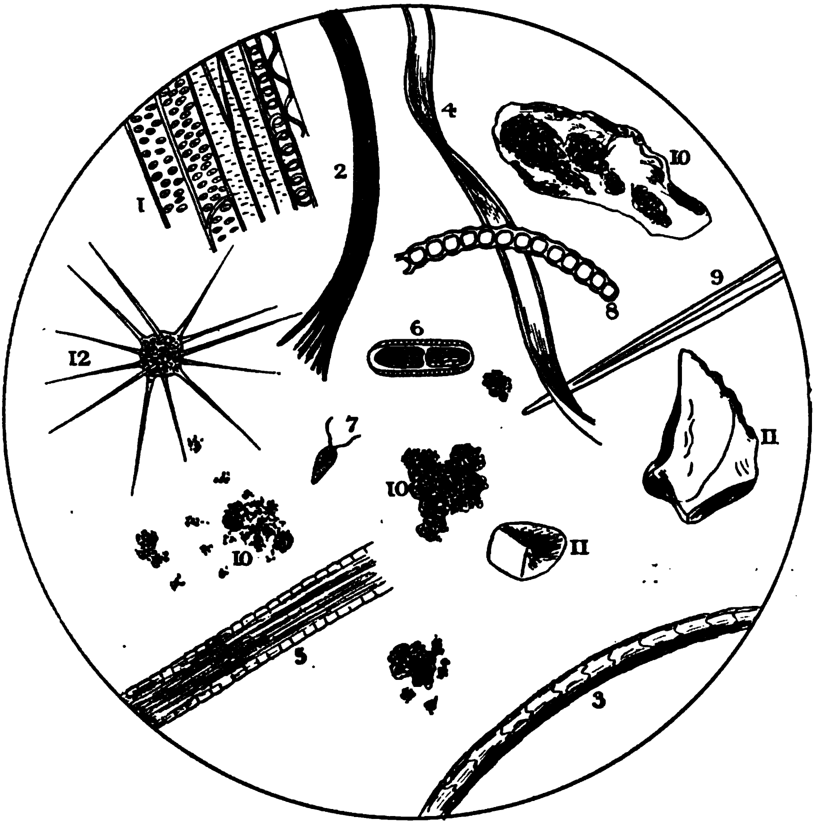
### DEPOSIT ON THE SIDE OF A WELL

When examining a well, the water from which showed bacteriologically and microscopically, but not chemically, certain signs of pollution, a little discoloration was observed on the brickwork near the point where the pump pipe entered the well. The microscopical examination of this proved that impure water was entering at this spot, and it was doubtless derived from slop water which was poured down the defective drain near the pump.

1. Various wood cells from some dicotyledon.
2. Fibre of hemp.
3. Fibre of wool.
4. Fibre of cotton.
5. Probably the hair of some animal.
6. A desmid (Penium).
7. A zoospore.
8. Dead algal filament.
9. Animal spine.
10. Particles of clay and brick.
11. Particle of sand.
12. A Radiolarian. S.K. Protozoa. Class Rhizopoda.

Magnified about 300 diameters.

## PLATE VIII



## PLATE IX

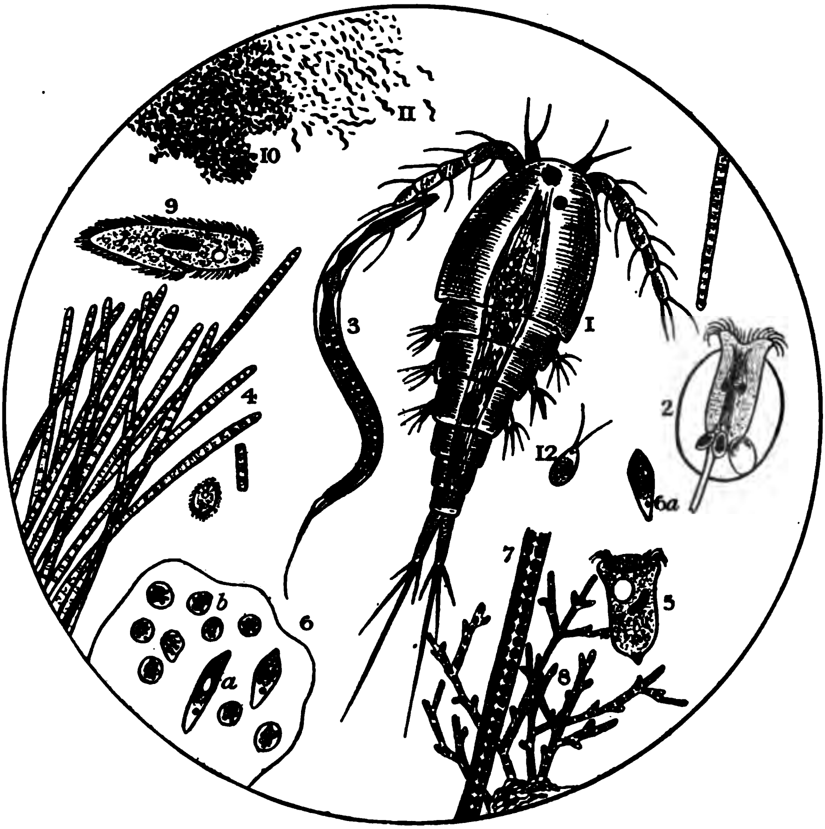
### WATER FROM A SMALL STREAM OR DITCH RECEIVING THE OVERFLOW FROM A CESSPOOL

This water is typical of many used in rural districts. Only a very few of the multitude of organisms found in the water are here depicted.

1. A cyclops. These small crustaceans abound in ponds and ditches.
2. A rotifer in sheath, with cilia expanded.
3. A nematode or thread-worm.
4. Oscillatoria of dark blue green colour, with oscillatory and sinuous movements. Attached to débris floating on the water. Probably Oscillatoria antliaria.
5. A free-swimming Vorticella.
6. Euglena viridis in a gelatinous sheath. (*a*) In motion; (*b*) at rest.
7. Green algal filament.
8. A dark green branching alga (Microthamnion ?).
9. Paramœcium Aurelia.
10. Vegetable débris with
11. Spirilla and bacilli.
12. Zoospore of alga with cilia and eyespot.

1, 2, & 3 magnified about 50 diameters, the others 300 diameters.

# PLATE IX



## PLATE X

### ORGANISMS FROM VARIOUS SOURCES

1. Gammarus pulex. A crustacean very prevalent in waters rich in vegetable matter.

2. Two species of Vorticella attached to portion of the body of a Gammarus.

3. Euplotes Charon, side view. 3*a*. The same organism, ventral aspect.

The above were found in a Chichester well water, and proved the presence of surface pollution.

---

4. A large infusorian. 4*a*. The same, contracted.
5. The encysted form of some infusorian.
6. Beggiatoa alba.

These were found in the effluent from a sewage works.

---

7. A rotifer (Floscularia ornata) in sheath. 7*a*. Some extended, showing cilia.

8. Macrobiotus or water bear, containing ova, 8*a*.
9. Larva of gnat.

From a rainwater tank.

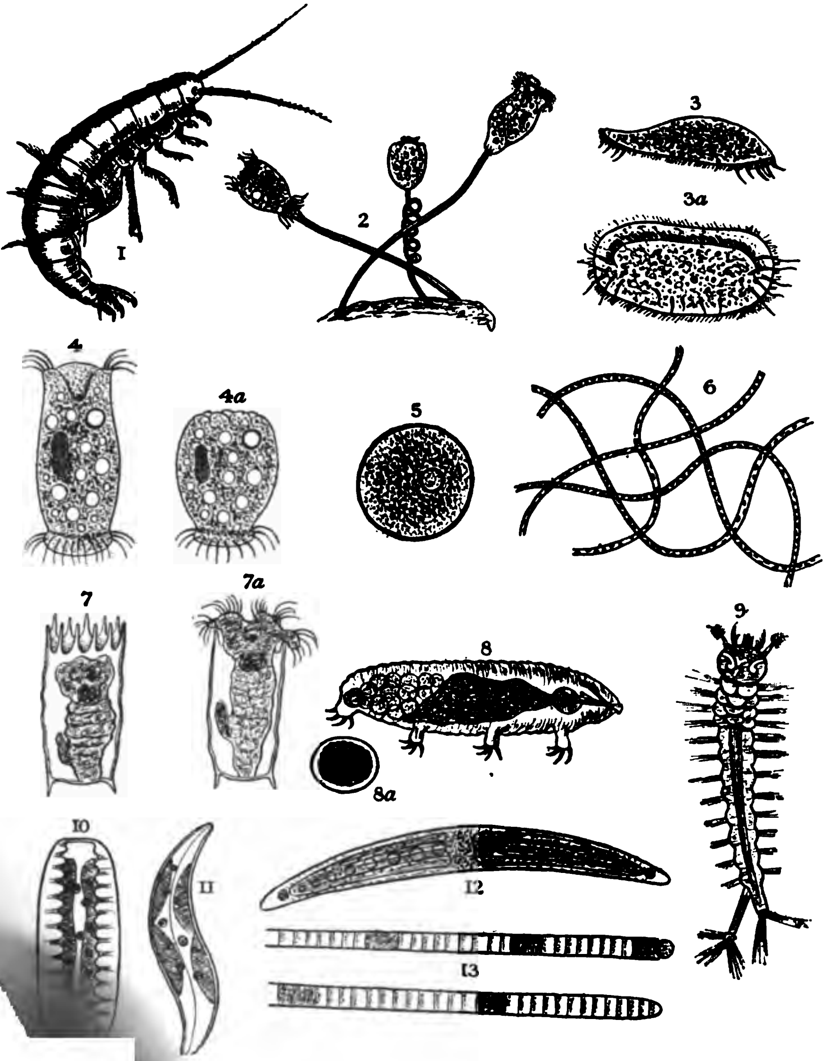
---

10 & 11. Diatoms (Surirella and Pleurosigma).
12. A desmid (Closterium).
13. A large form of Oscillatoria.

From river Blackwater. Pollution very slight.

Nos. 1 & 9 magnified about 10 diameters, the others about 250 diameters.

# PLATE X



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3. Euplotes Charon, side view. *3a.* The same organism, ventral aspect.

The above were found in a Chichester well water, and proved the presence of surface pollution.

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5. The encysted form of some infusorian.

6. Beggiatoa alba.

These were found in the effluent from a sewage works.

7. A rotifer (Floscularia ornata) in sheath. *7a.* Some extended, showing cilia.

8. Macrobiotus or water bear, containing ova, *8a.*

9. Larva of gnat.

From a rainwater tank.

10 & 11. Diatoms (Surirella and Pleurosigma).

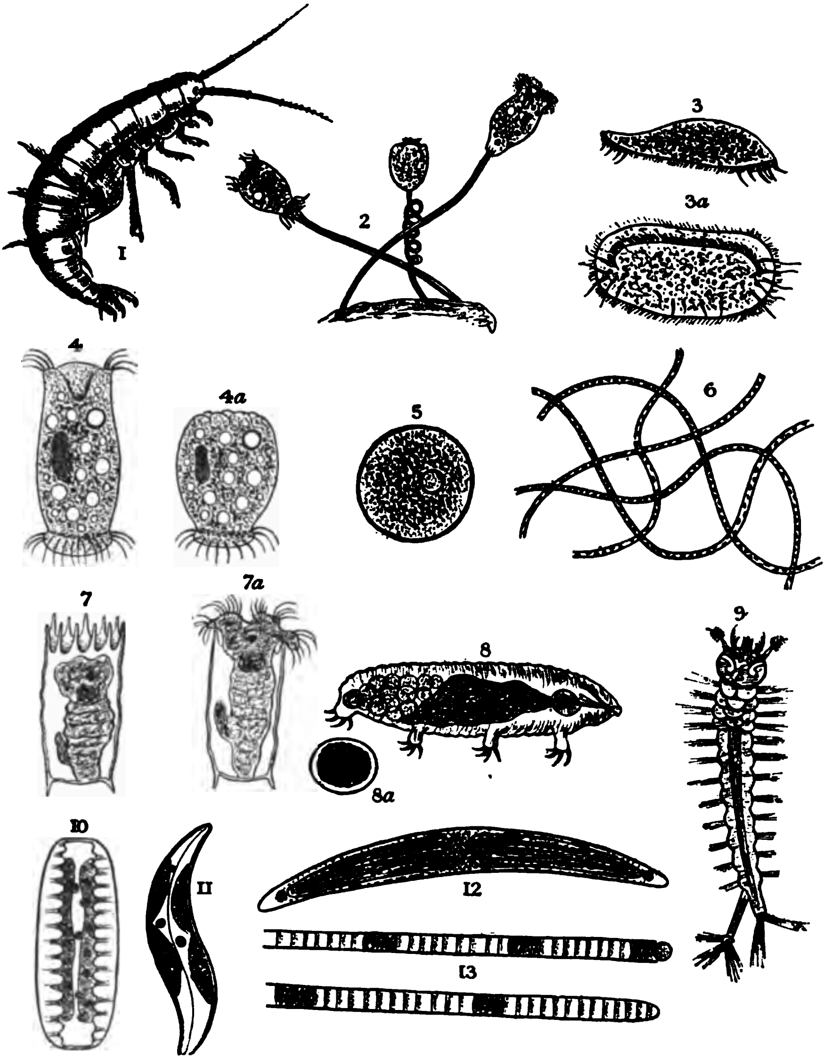
12. A desmid (Closterium).

13. A large form of Oscillatoria.

From river Blackwater. Pollution very slight.

Nos. 1 & 9 magnified about 10 diameters, the others about 250 diameters.

# PLATE X



## PLATE XI

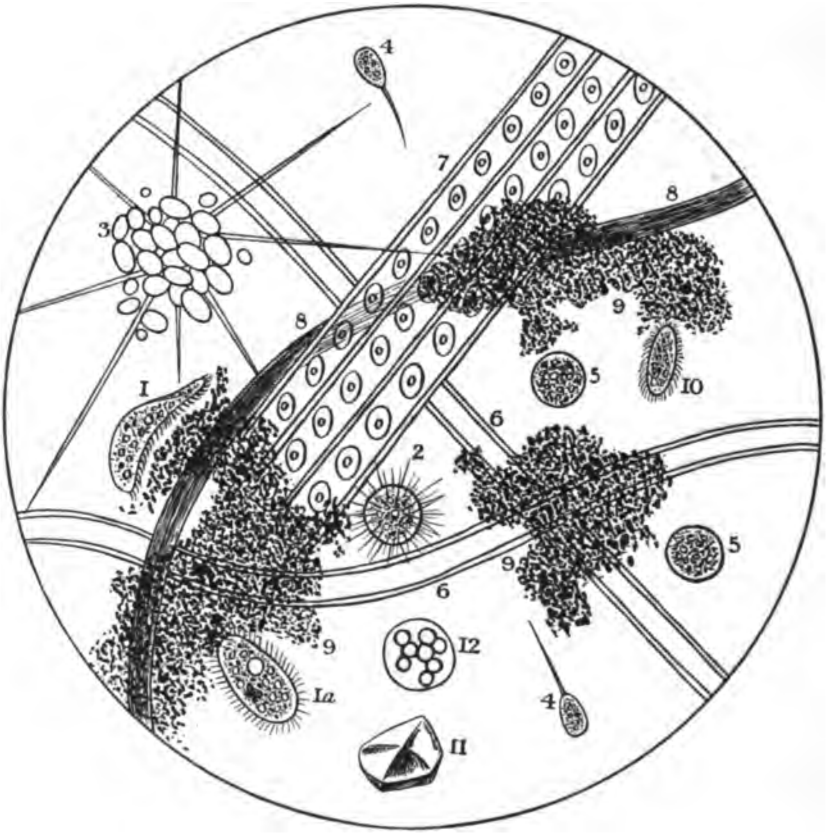
### SHALLOW WELL WATER FROM NEWPORT, SALOP

This water contained a good deal of particulate matter which settled to the bottom of the containing vessel in reddish flocculi. It was obviously of very unsatisfactory character. The microscope showed the presence of oxide of iron, and of animal and vegetable débris, denoting pollution.

1. Paramœcium, side view. 1*a*. Same, surface view.
2. Acanthocystis, one of the Heliozoa.
3. Aphanochæte (dead).
4. Zoospore of alga.
5. Encysted form of some protozoa.
6. Vegetable fibre.
7. Fragment of Conifer.
8. A hair. Very opaque, bluish tinge.
9. Vegetable débris with ferric hydrate.
10. A small paramœcium.
11. Particle of sand.
12. A slightly motile organism with very refractive granules.

All magnified about 300 diameters.

## PLATE XI



## PLATE XII

### WATER FROM A SHALLOW WELL

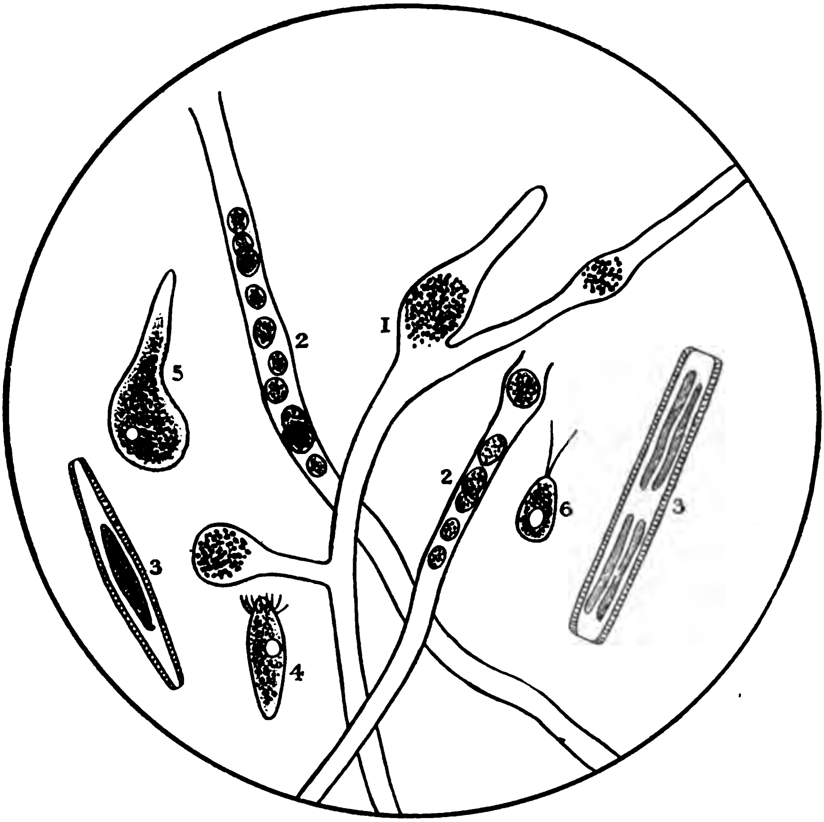
This water, good chemically, contained a very little fluffy matter which under the microscope revealed the undermentioned forms. Obviously the well had some defect.

1 & 2. Fungal hyphæ, with spores. This constituted the particles of fluffy matter seen in the water when held up to the light.

3. Diatoms.
4. Species of infusorian.
5. An amœba (Lobosa).
6. Zoospore of alga.

Nos. 1 and 2 magnified about 500 diameters, the others about 250.

## PLATE XII



## PLATE XIII

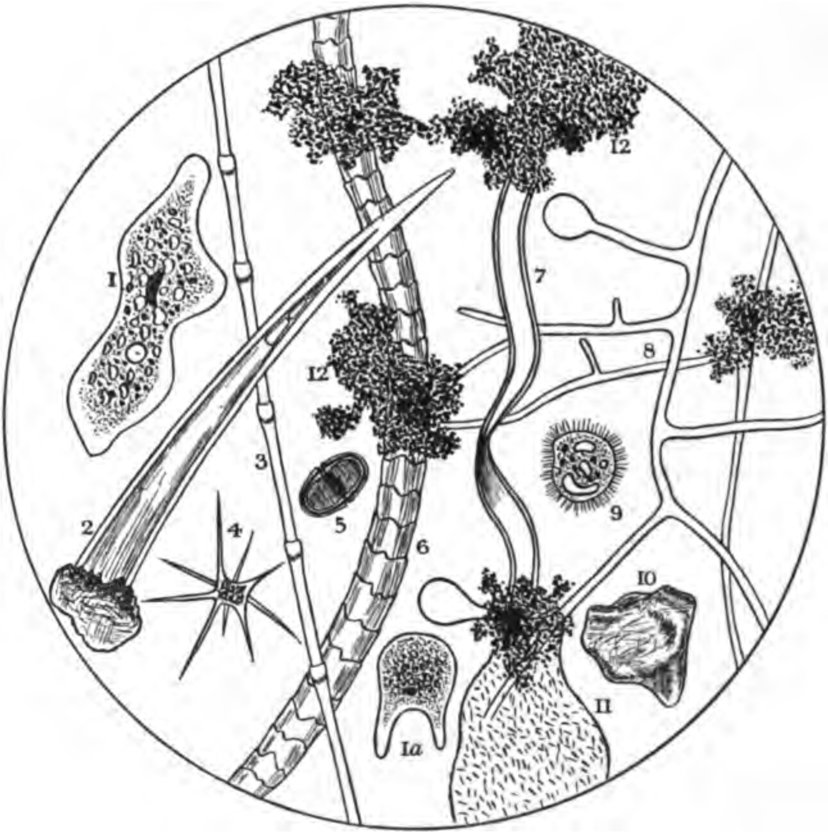
### WATER FROM A SHALLOW WELL AT WYMONDHAM

This water was chemically impure, and swarmed with bacteria. It was undoubtedly polluted with sewage matter.

1. Large amœba (Lobosa). 1*a*. A smaller form.
2. Animal spine.
3. Hair of some insect.
4. A form of Protomyxa.
5. A teleutospore.
6. Fibre of wool.
7. Vegetable fibre.
8. Fungal hyphæ, probably Saprolegnia.
9. Actinophrys.
10. Sand particle.
11. Zooglœa of bacteria.
12. Vegetable débris.

Magnified about 300 diameters.

# PLATE XIII



## PLATE XIV

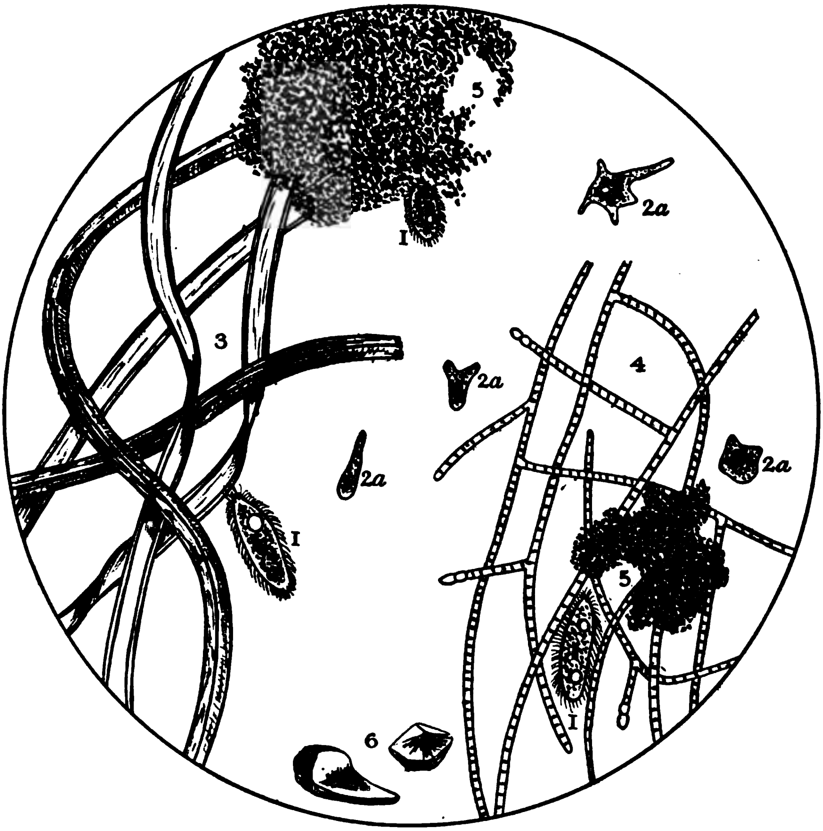
### WATER FROM A DEEP WELL

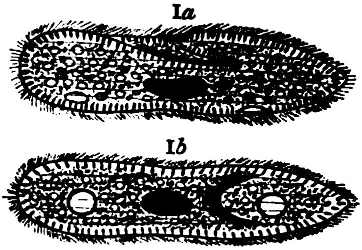
This water came from a bored well about 120 feet deep. The upper 20 feet was dug and lined with brickwork. About 20 yards away there was a tidal river, and there was a suspicion that either tidal water or subsoil water was entering the well. When, at a later date, the water was pumped out, a great quantity of water was seen to enter the well through defects in the brickwork. This confirmed the opinion formed from the examination of the water.

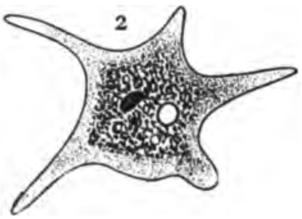
1. Paramœcia.
1*a*. Paramœcium Aurelia. Side view } The vacuoles open and
1*b*. Paramœcium Aurelia. Surface view } close alternately.
2. An amœba.
2*a*. Various amœba.
3. Human hair and vegetable fibres.
4. Fungal hyphæ, forming spores.
5. Decaying vegetable débris.
6. Particles of sand.

1–6 magnified about 250 diameters.
1*a* and 1*b* more highly magnified.

# PLATE XIV







## PLATE XV

### WITHAM PUBLIC WATER SUPPLY

This supply is derived from two sources, one a deep well, the other a spring rising in an arable field. During last autumn particles of matter resembling boiled potato were found in the water from the house taps, and when the mains were flushed large masses of this material appeared.

The water was sent to me for examination. Chemically the water was satisfactory, biologically and bacteriologically it was decidedly unsatisfactory. I have never seen anything of this kind before, nor can I hear of a similar phenomenon having been observed elsewhere.

After standing some days the water acquired an offensive odour.

1. Zoogl&oelig;a of micrococci, 1*a*, each with a distinct gelatinous envelope.

2*a*, 3*a*, & 4*a*. Organisms embedded in the zoogl&oelig;a; some also, 2, 3, & 4, seen floating free in the water.

5 & 6. Anguillulæ. N.O. Nematoda.

7. Diatoms, very abundant in the zoogl&oelig;a.

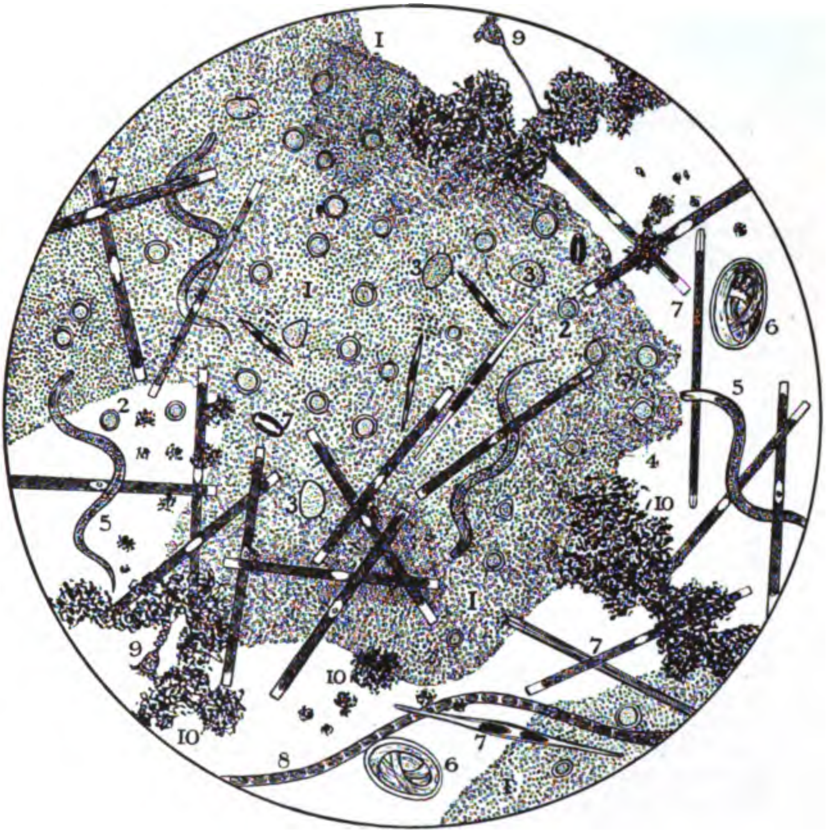
8. Algal threads.

9. Vorticella.

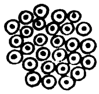
10. Apparently vegetable débris. It was of a red-brown tint, and contained a trace of iron.

By persistent flushing of the mains the growth at length disappeared, and no trouble has been experienced since.

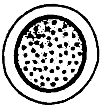
# PLATE XV



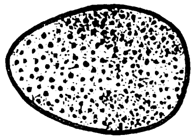
I.*a*.



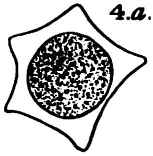
2.*a*.



3.*a*.



4.*a*.



# PLATE XVI

## SCRAPING FROM THE SURFACE OF A LARGE SAND FILTER USED FOR THE PURIFICATION OF THE SUPPLY TO A LARGE TOWN

The water was in part derived from springs and in part from surface of more or less cultivated land. The dried surface of the sand was covered with a thin semi-transparent film of a brownish-green colour.

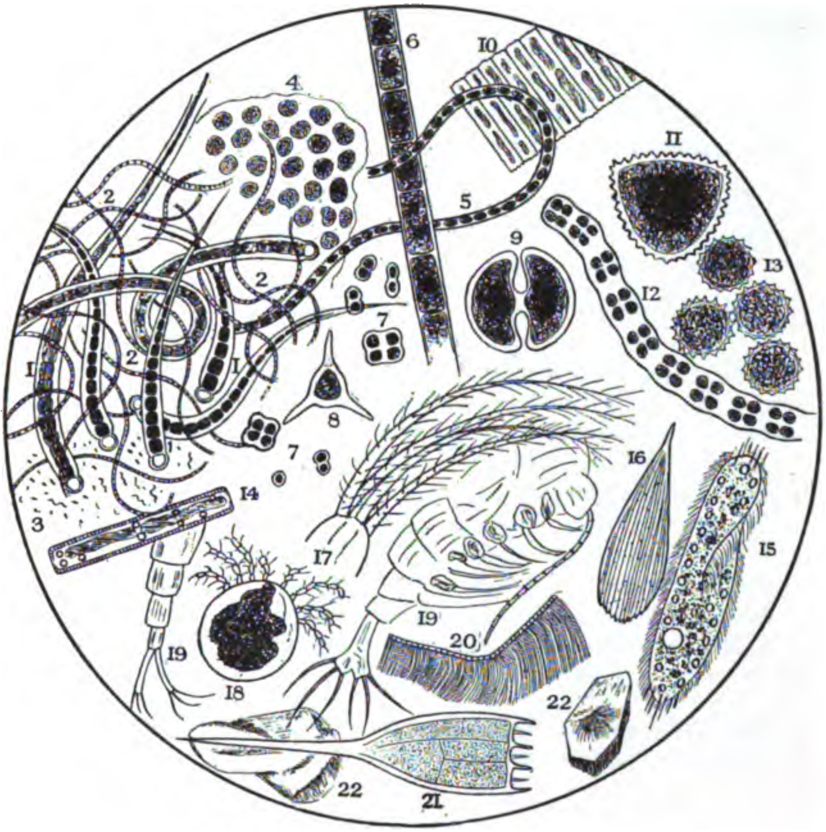
1. Rivularia and allied forms, which with
2. Beggiatoa formed the larger portion of the felted mass covering the sands.
3. Bacilli and spirilla.
4. Palmella embedded in jelly.
5. A conferva.
6. Probably a species of Zygnema.
7. Pleurococcus.
8. A desmid (Staurastrum).
9. A desmid (Cosmarium).
10. A diatom (Fragilarieæ).
11. A desmid.
12. An algal filament.
13. Probably pollen.
14. Diatom (Pinnularia).
15. Stylonychia.

16–20. Dead and disorganised animal remains. (16. Scale from wing of moth. 18. A mite. 19. Cyclops.)

21. Sheath of rotifer.
22. Sand particles.

1–15 magnified about 100 diameters.
16–21 magnified about 50 diameters.

# PLATE XVI



## PLATE XVII

### SCRAPINGS FROM THE SURFACE OF A FILTER BED USED IN CONNECTION WITH A LARGE STORAGE RESERVOIR COLLECTING UPLAND SURFACE WATER

This plate contains only a few of the organisms identified, but they were the most abundant. Associated with these was much vegetable débris, not shown in the drawing.

1. Bands of diatoms (Fragilarieæ). Girdle view.

1*a*. Separate diatom. Valve view.

2. Hydrodictyon. This organism is, by many, considered to be a desmid, in which the cells after division remain connected and form a network. It is a freshwater alga. Cooke regards it as a sub-family of the Palmellaceæ.

3. Actinosphærium. A rhizopod.

4. Filaments of a Spirogyra.

5. Diatom (Synedra). Valve view.

5*a*. Diatom (Synedra). Girdle view.

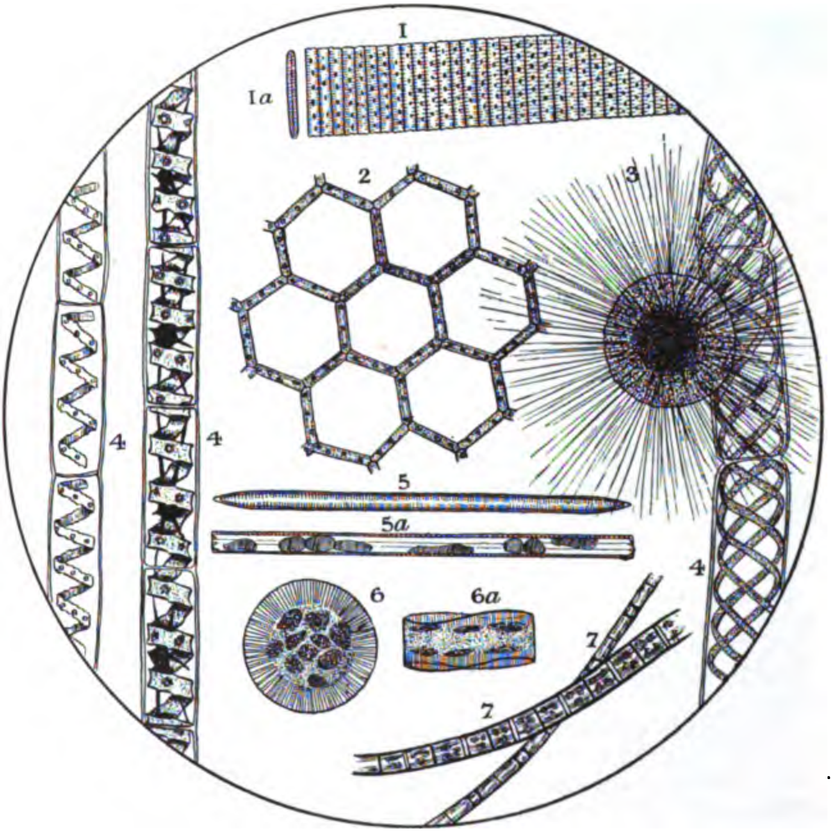
6. Cyclotella, a discoid diatom. Valve view.

6*a*. Cyclotella, a discoid diatom. Girdle view.

7. Melosira. Discoidal diatoms forming filaments. Closely allied to No. 6.

Nos. 2 & 3 magnified 100 diameters; No. 4, 200 diameters; Nos. 1, 5, & 7, 250 diameters; No. 6, 500 diameters.

## PLATE XVII



## PLATE XVIII

### ORGANISMS FROM VARIOUS SOURCES

1. An Anabæna. Family Nostocaceæ. From a water with a horse-dung odour.

2. Beggiatoa alba. From outfall of a land drain from a sewage farm.

3. A species of Nostoc. From a ditch water. Said sometimes to cause water to become odorous.

4. Sphærotilus natans. (*a*) Natural size; (*b*) an enlarged thread. From a stream polluted with sewage and manufacturing refuse.

5. Conferva bombycina. Source, pond water.

6. Spongilla fluviatilis. (*a*) Natural size on twig; (*b*) spicules; (*c*) animal cells forming the sarcode of the sponge. Source, mountain stream.

7. (*a*) Macro- and micro-spores of Crenothrix polyspora; (*b*) tufts of thread formed by germination of spores in parent thread. (Zopf.) *Vide* Plate II, No. 24.

8. Volvox globator. This organism was found in myriads recently in a reservoir, the water of which had fallen very low. Odour on standing became fishy.

9. Leptomitus lacteus. From an impure river water.

10. Cryptomonas. A flagellate infusorian, from a pond water, said sometimes to impart a 'violet' odour to water.

11. Bursaria gastris. Said to have imparted a seaweed-like odour to water.

12. Carchesium Lachmanni. From luxuriant growth in sewage-polluted brook.

13. Tabellaria. A diatom found in waters with an 'aromatic' odour.

14. Asterionella formosa. A diatom said to give an 'aromatic' odour to water.

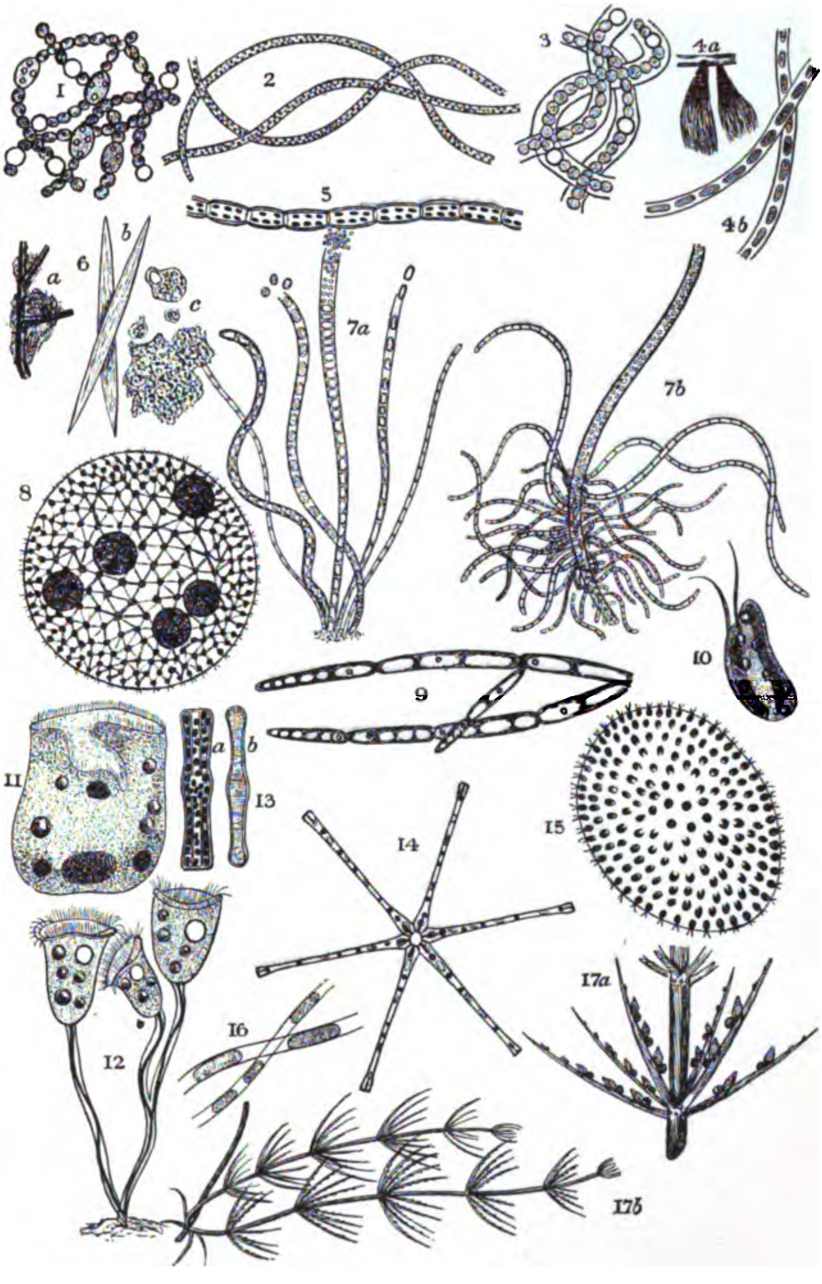
15. Uroglena, species of. Often mistaken for Volvox. Said to impart an 'oily' or 'fishy' odour to water.

16. Filament of a species of Lyngyba. A freshwater alga, said to impart a disagreeable odour to water.

17. Chara, (*a*) showing reproductive organs. (*b*) C. fragilis, showing fertile and barren branches. (After Oliver.)

Nos. 8, 11, & 16 magnified 100 diameters. 17*a* slightly enlarged, 4*a* & 6*a* natural size, 17*b* slightly reduced. All others magnified 250 diameters.

# PLATE XVIII



## PLATE XIX

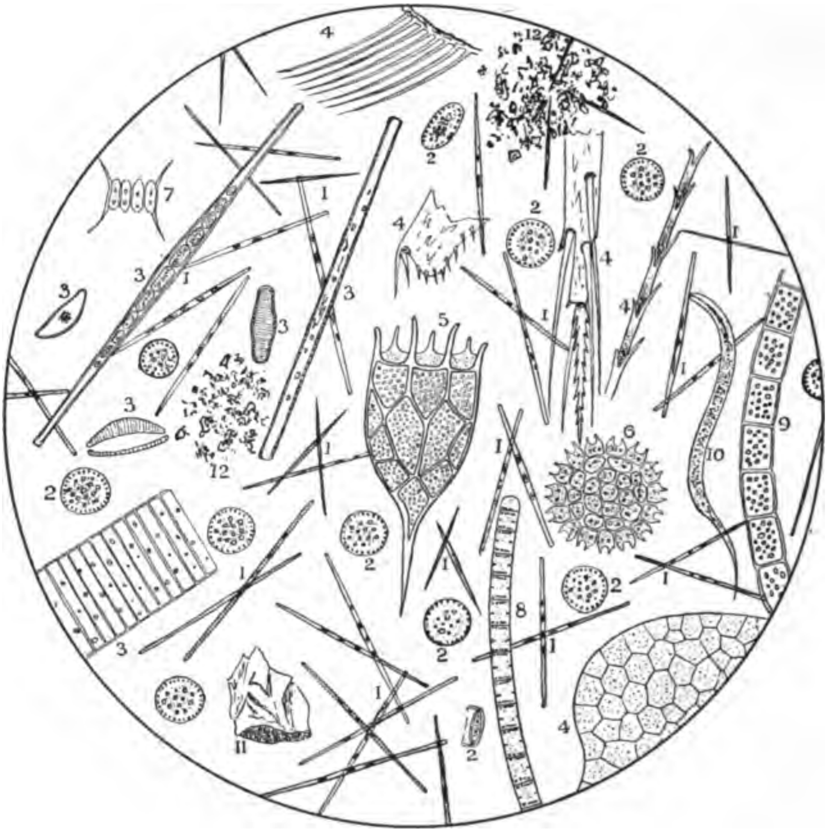
### SEDIMENTARY MATTER FOUND IN A FILTERED WATER

A moorland water was passed through a series of mechanical filters, yet complaints arose about turbidity and discoloration of the water. The Water Authority blamed the filters, the filter-makers resented the imputation. The filters were not very efficient, but the growth was taking place in a large and practically open storage reservoir. When the filtered water ran directly into the mains, the trouble ceased. This was done until the reservoir could be cleaned and properly covered.

1. Diatoms. Naricula sp.
2. Diatoms. Stephanodiscus sp.
3. Diatoms. Various species.
4. Remains of crustaceans.
5. Sheath of a Rotifer. Anurea sp.
6. Desmid. Pediastrum sp.
7. Desmid. Scenedeomus sp.
8. Oscillaria sp.
9. Algal thread.
10. Anguillula sp.
11. Sand.
12. Organic débris.

4 & 5 magnified about 100 diameters.
Others magnified about 300 diameters.

## PLATE XIX



# PLATE XX

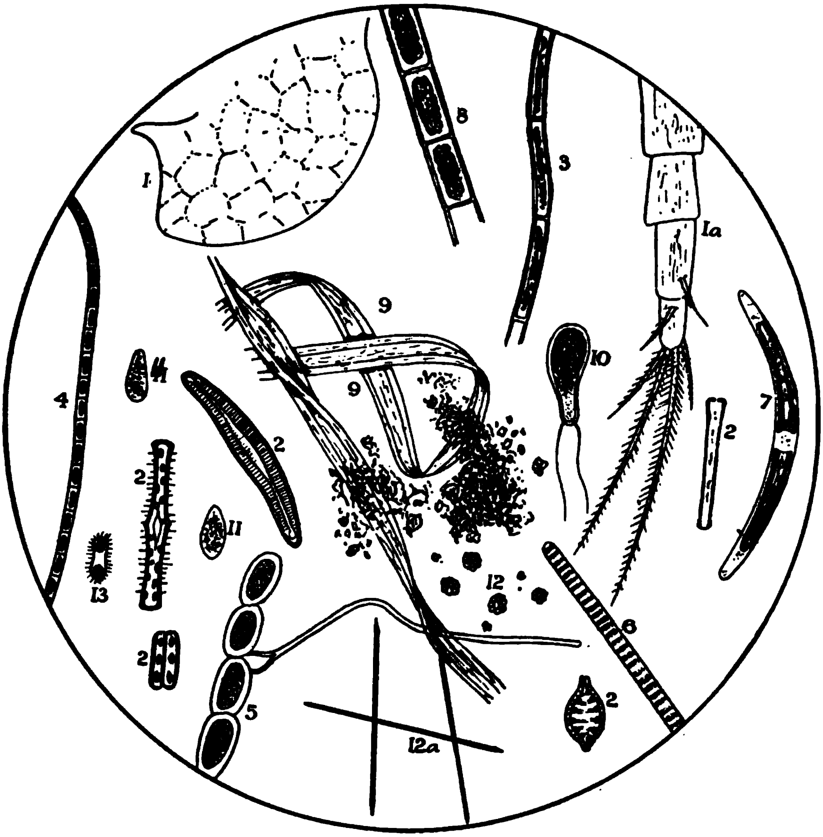
## DEPOSIT FROM A MOORLAND WATER

Derived from a brook, the water from which, after passing through a bed of coarse sand, supplied a large community. The filtration was very imperfect. A marked deposit formed in a winchester of the water; in this deposit the forms of animal and vegetable life depicted upon this plate were observed.

1. Carapace of a cyclops. 1*a* Tail of cyclops.
2. Diatoms.
3, 4 & 8. Algal threads.
5. Bulbochæte.
6. Oscillaria sp.
7. Desmid. Closterium sp.
9. Cotton fibre.
10. A large monad.
11. A very active infusorian.
12 & 12*a*. Crystals.
13. Probably a desmid.

No. 1 magnified 100 diameters, the remainder × 300.

# PLATE XX



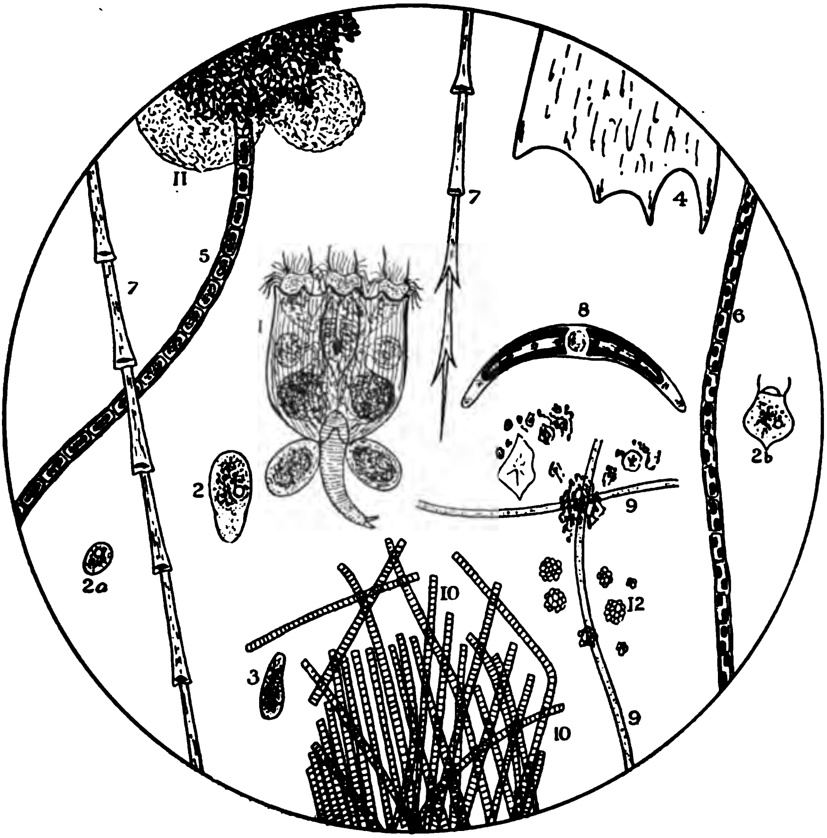
## PLATE XXI

Lake or reservoir water proposed to be utilised for the supply of a town in South Wales. Filtration absolutely necessary, though there were no sources of pollution on the gathering ground.

1. Rotifer (Brachionus urceolata) in sheath, with ova.
2. Probably an amœba (?).
2*a*. A motile organism (?). No visible cilia.
2*b*. An infusorian (?).
3. An active and abundant infusorian.
4. Portion of carapace of some minute crustacean.
5 & 6. Algal threads sp.
7. Hairs of insects.
8. Desmid (Closterium sp.).
9. Fungus in débris.
10. Oscillaria in masses.
11. Zooglœa of bacteria.

No: 1 magnified about 60 diameters.
Others magnified about 250 diameters.

# PLATE XXI



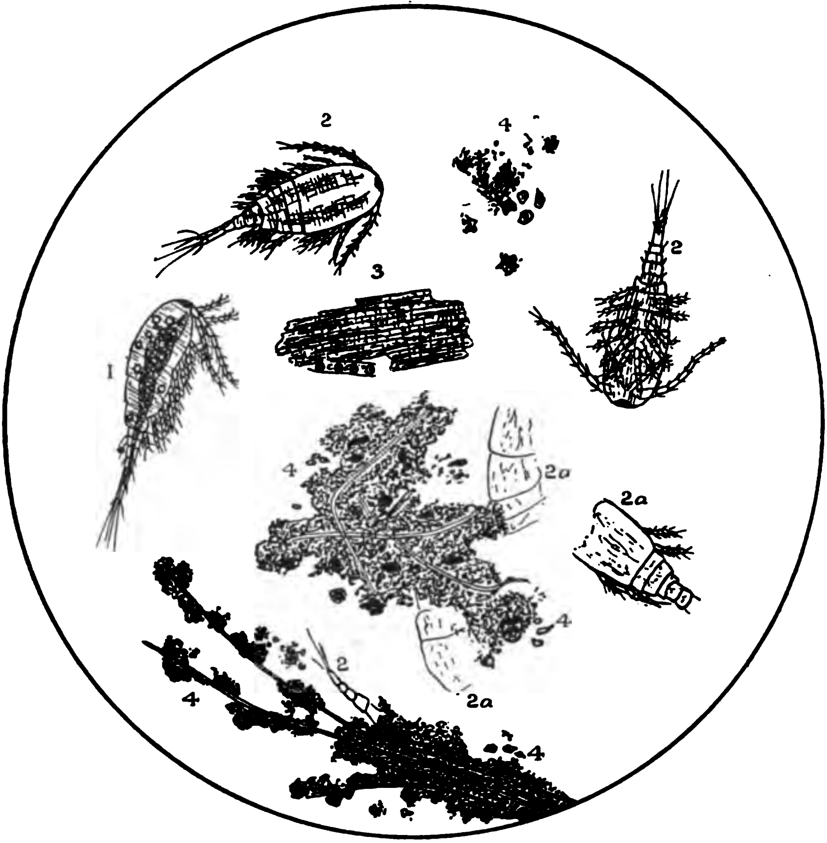
## PLATE XXII

A cyclops-infested water supply. Source from upland surfaces. Water not filtered before delivery.

1 & 2. Cyclops quadricornis.
3. Portions of carapace of same.
4. Fungus in débris.

1 to 3 magnified about 50 diameters.
4 magnified about 250 diameters.

# PLATE XXII



## PLATE XXIII

Water from a stream utilised as a public supply. Liable to pollution from farms, &c., above the intake.

1. Probably a mandible of some insect.
2. Cotton, or cellulose threads.
3. Probably a thread of hemp.
4. Diatom. Surirella sp.

5, 6 & 7. Algal threads, various species.

8. Small amœba.

9 & 9*a*. Probably resting-stage of some infusorian.

10. (?)

11. Desmid. Closterium sp.

11*a*. Desmid. Penium sp.

12. An infusorian sp. (?)

13. Euplotes sp. An infusorian.

14. Threads of a rather large Beggiatoa.

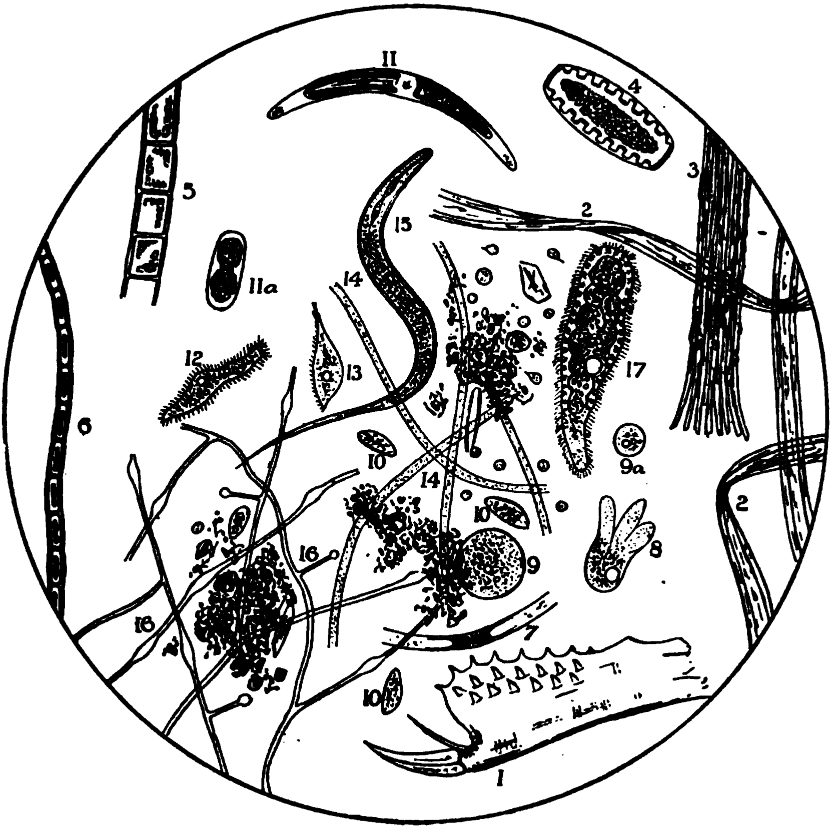
15. Anguillula.

16. Fungus and débris.

17. A rather large infusorian, showing a very distinct vacuole.

All magnified about 300 diameters.

# PLATE XXIII



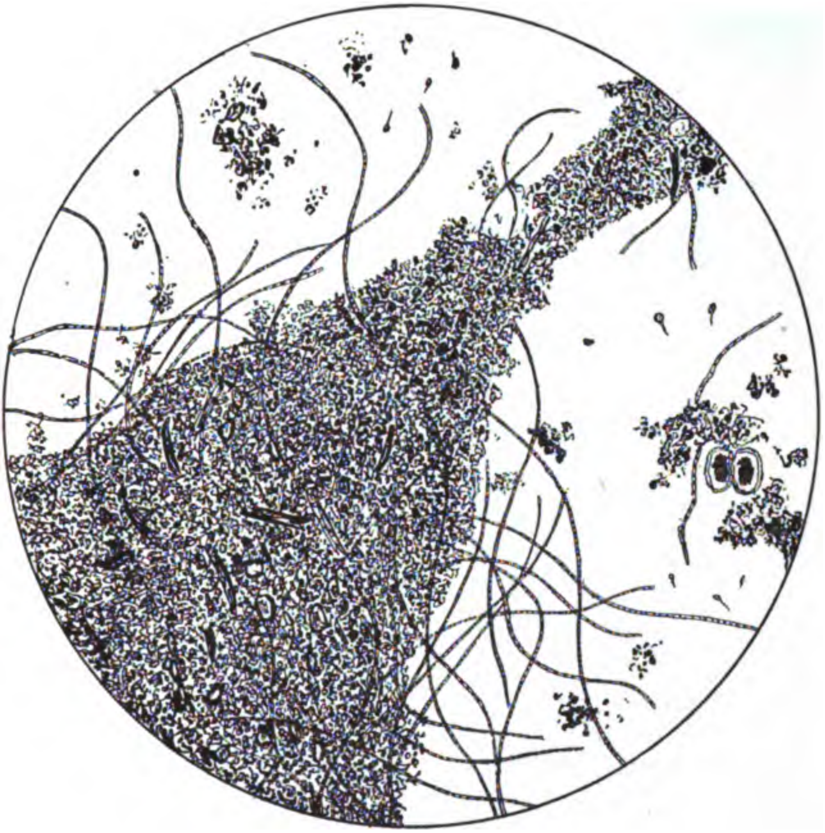
## PLATE XXIV

**From a polluted water submitted for examination. Source not stated.**

**A mass of débris, in which is embedded a thread fungus, Beggiatoa.**

**Magnified about 300 diameters.**

PLATE XXIV



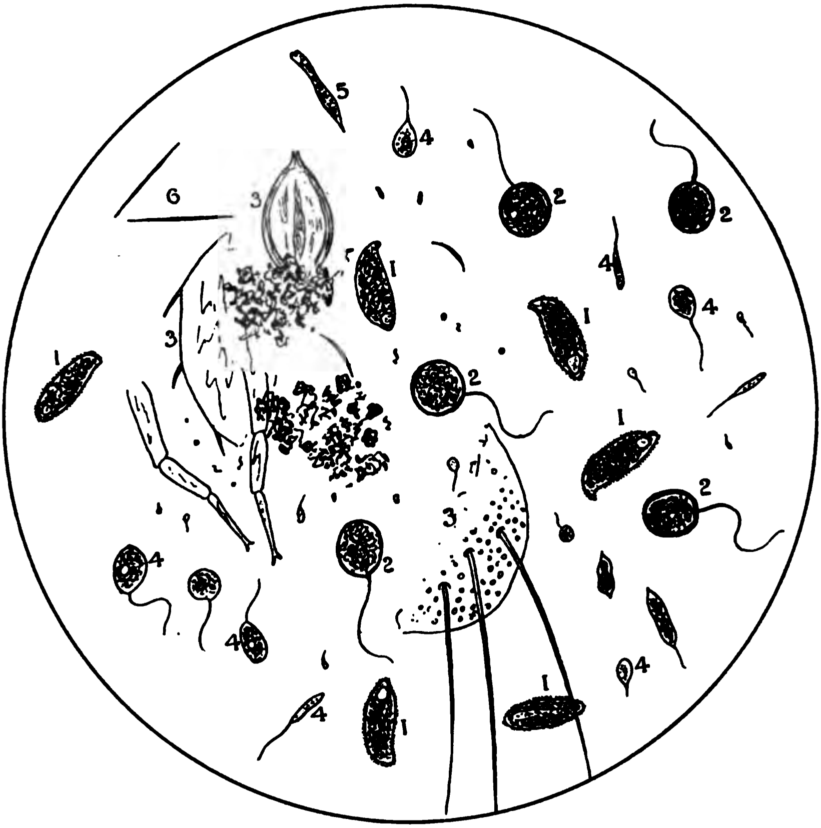
## PLATE XXV

Growth in an open service reservoir. Water had been imperfectly filtered.

1. Ciliate infusorians, sp.
2 & 4. Flagellate infusorians, various sp.
3. Disorganised remains of minute animals.
5. Small form of Euglena viridis.
6. Crystals (?).

No. 3 magnified about 300 diameters.
Others magnified about 500 diameters.

PLATE XXV



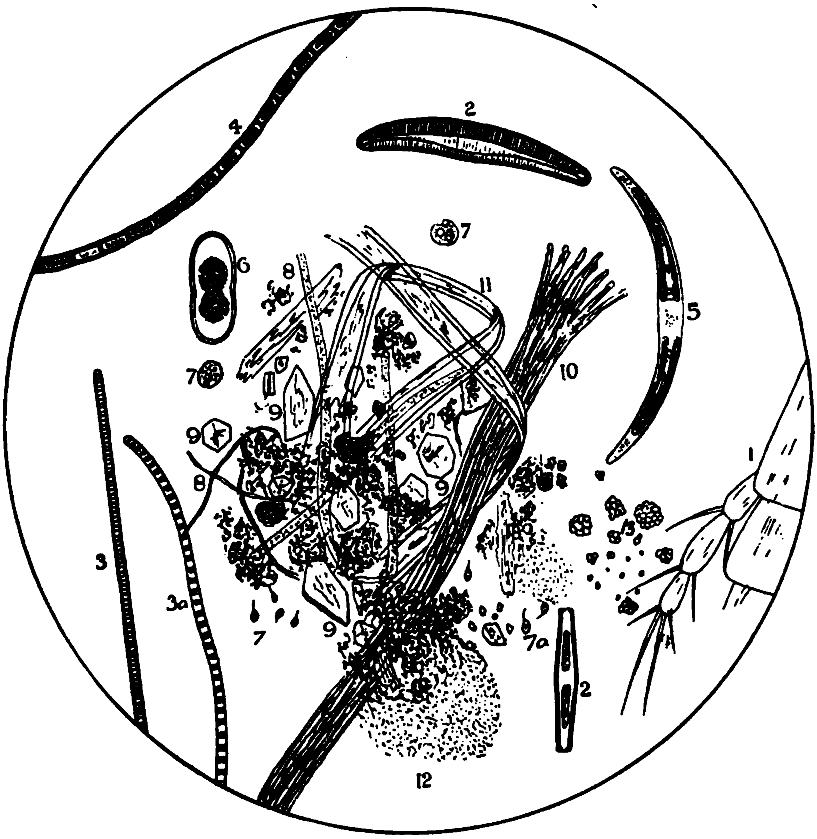
## PLATE XXVI

From an open well liable to pollution with every rainfall.

1. Portion of a cyclops.
2. Diatoms, various species.
3 & 3*a*. Oscillaria sp.
4. An algal thread.
5. A desmid (Closterium sp.).
6. (?)
7. Minute infusorians.
8. Fungæ hyphæ.
9. Sand and débris.
10. Probably a fibre of hemp.
11. Cellulose fibres, probably cotton.
12. Zooglœa of bacteria.

All magnified about 300 diameters.

## PLATE XXVI



## PLATE XXVII

From a large reservoir on the Derbyshire Moors.

1. Larva of some two-winged fly.
2. Diatoms, Fragilaria, sp.

3 & *3a*. Diatoms, probably Surirella sp.

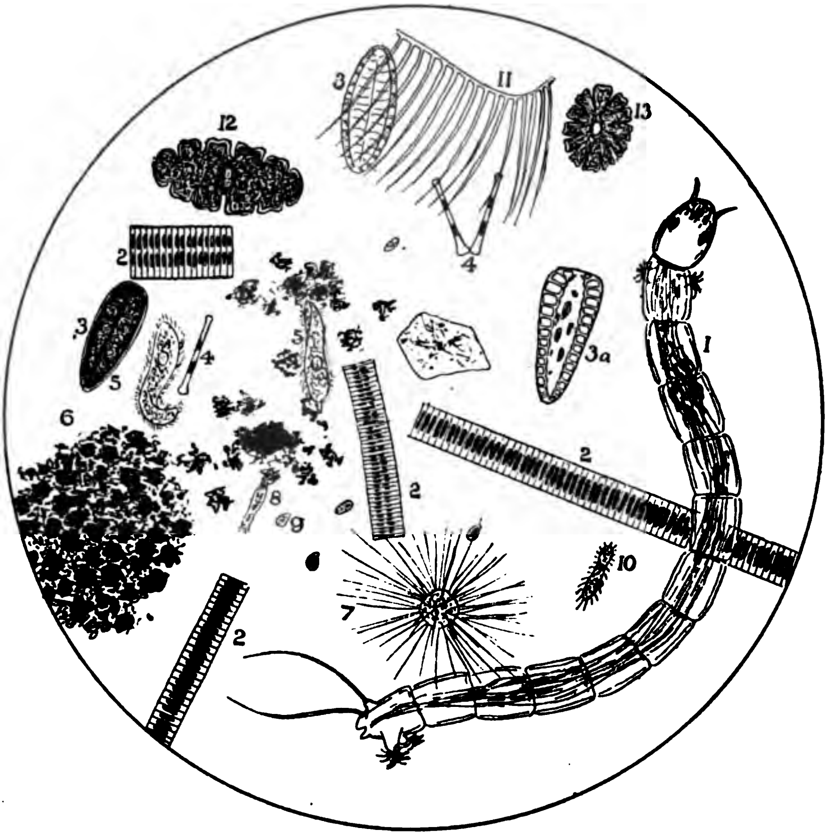
4. Diatoms, Asterionella, sp.
5. Infusorians, species of paramœcia.
6. Case of mud inhabited by the larva (1).
7. Actinophrys sol.

8 & 9. Small infusorians.

10. Small infusorians with fewer and more rigid cilia.
11. Portions of a minute animal.
12. A desmid, Euastrum, sp.
13. A desmid, Pediastrum, sp.

1 & 6 magnified about 50 diameters.
Others magnified about 250 diameters.

# PLATE XXVII



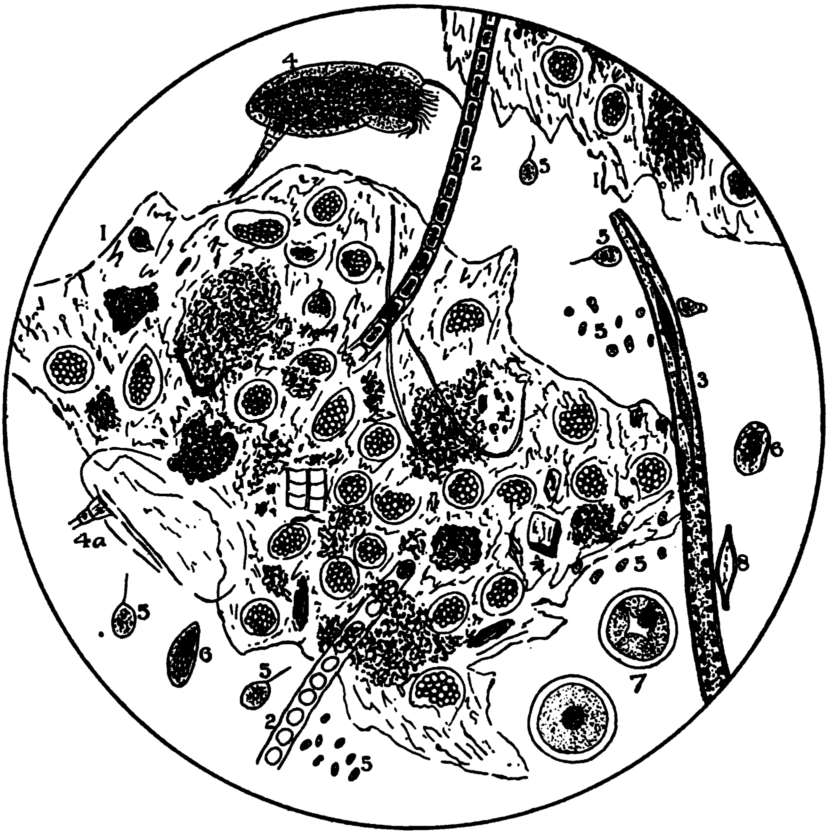
## PLATE XXVIII

From a house-tap. Moorland water alleged to have been filtered.

1. Probably palmella, embedded in jelly, with which is associated animal and vegetable remains.
2. Algal threads.
3. Portion of Anguillula.
4. A rotifer sp. 4*a*. Disorganised remains of same.
5. Minute flagellate. Infusorians.
6. (?)
7. Probably ova of some minute animal.
8. Diatom sp.

4 & 4*a* magnified about 300 diameters.
Others magnified about 500 diameters.

## PLATE XXVIII



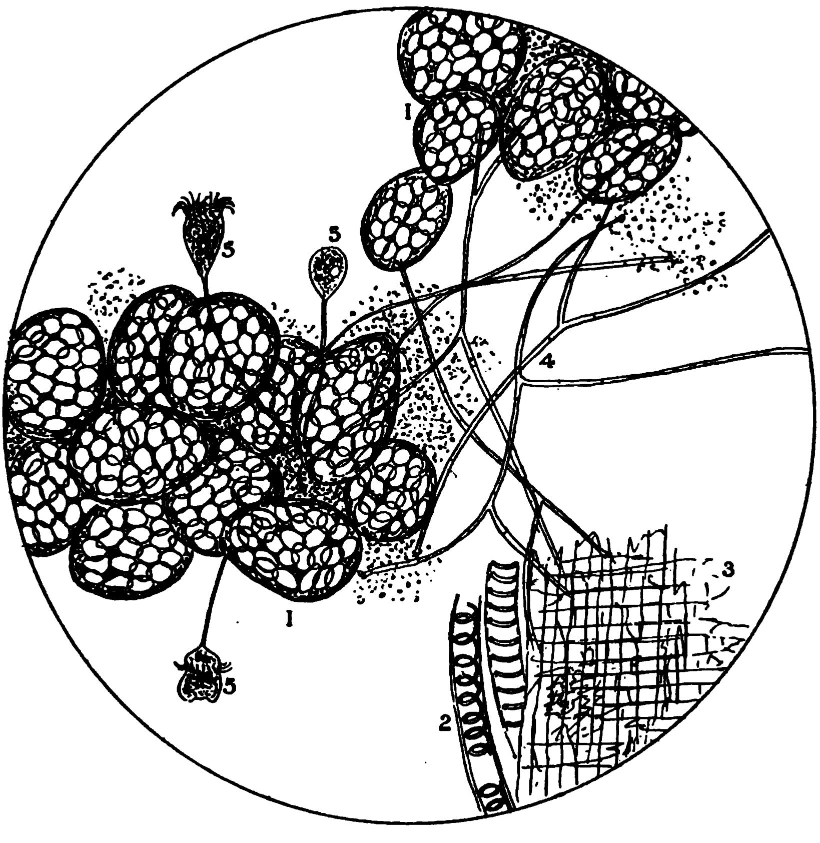
## PLATE XXIX

Shallow well. Public supply to a village.

1. Vegetable cells, containing starch.
2 & 3. Vegetable fibres.
4. Fungal hyphæ.
5. Vorticella.

All magnified about 200 diameters.

PLATE XXIX



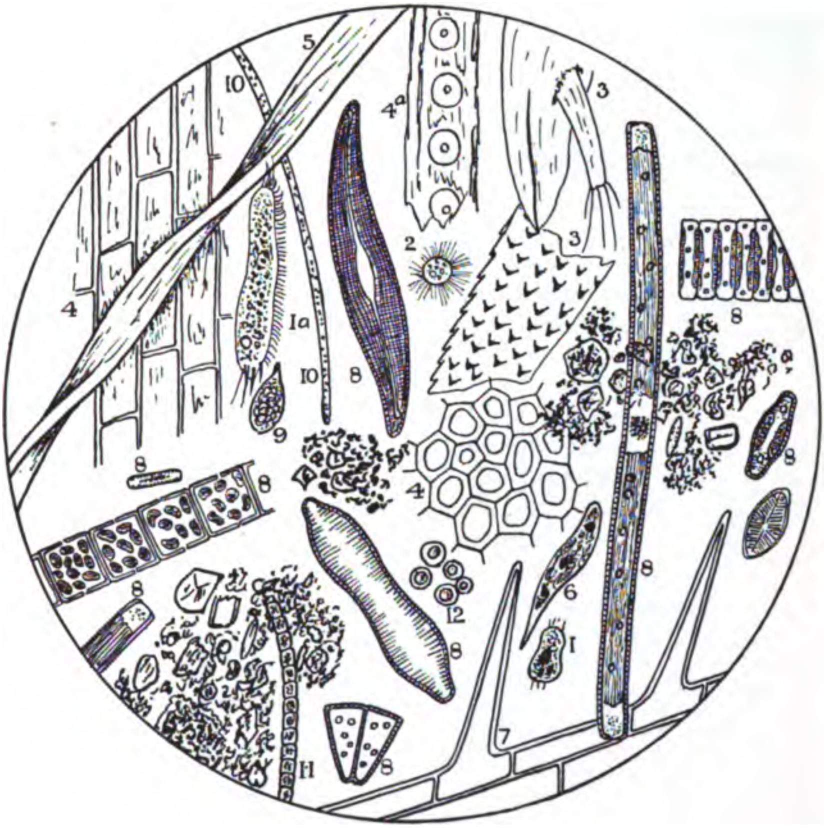
## PLATE XXX

River-water just above the intake of a Water Company, Norfolk.

1. Small infusorian, sp.
1*a*. Infusorian. Stylonychia.
2. Species of actinophrys.
3. Animal remains, probably portions of small crustaceans.
4. Vegetable débris.
4*a*. Coniferous wood-fibre.
5. Cellulose fibres.
6. Euglena viridis.
7. Vegetable hairs.
8. Various diatoms.
9. (?)
10. Thread of Beggiatoa.
11. Alga in débris.

Magnified about 400 diameters.

# PLATE XXX



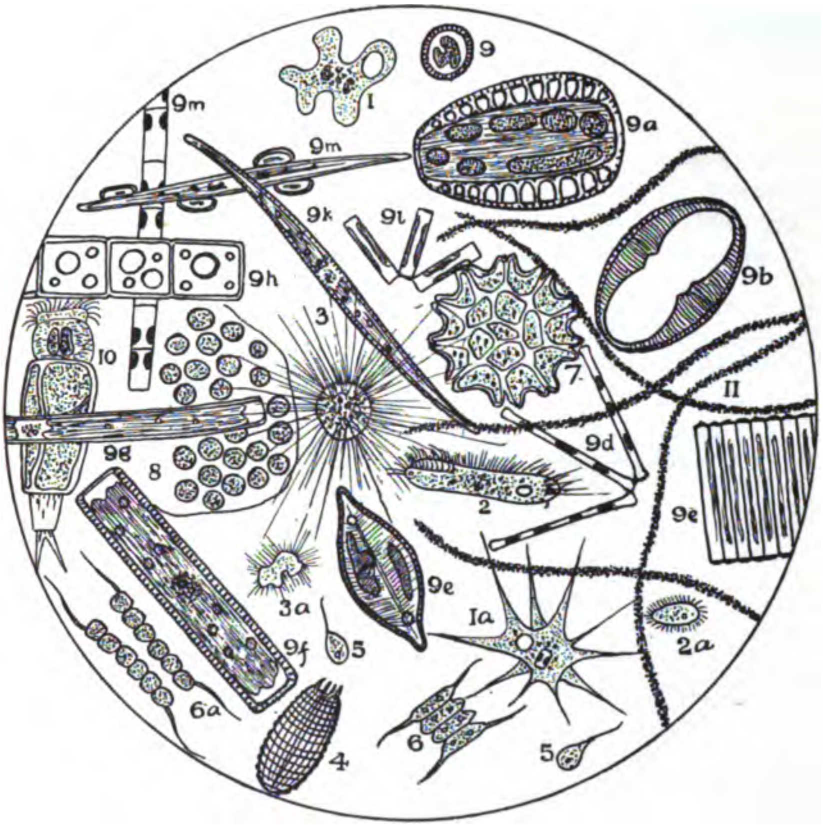
## PLATE XXXI

Water from river connecting certain Norfolk Broads. (It is stored and filtered, and then used for a public supply.)

1. Amœba.
1*a*. An allied form.
2. An infusorian. Stylonychia sp.
2*a*. Small infusorian.
3. A radiolarian. Actinophrys sol.
3*a*. An allied form.
4. Coleps hirta.
5. A monad, very active.
6. A desmid. Scenedesmus.
6*a*. An allied form.
7. A desmid. Pediastrum Boryanum.
8. Palmella mucosa, embedded in jelly.
9. *a–n*. Various diatoms.
10. A rotifer, probably R. vulgaris.
11. Fungæ hyphæ with iron oxide (?). Cladothrix.

No. 10 magnified about 100 diameters.
Others magnified about 250 diameters.

## PLATE XXXI



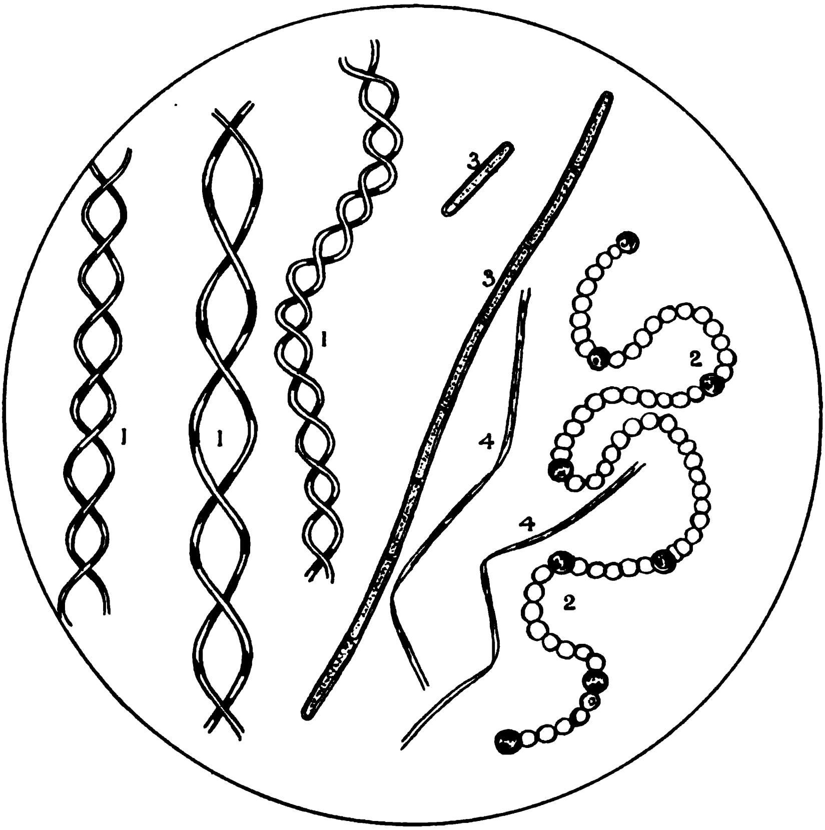
## PLATE XXXII

Growth on exposed surface of chalk round fissures from which water was issuing. Chalk had become impregnated with bisulphite liquor from a paper pulp works.

1. Predominating organism in sample. Apparently double spirilla, and probably one of the coloured, sulphur-bearing family.
2. Either a very small Nostoc or the sugar-bacterium (Leuconostoc) without gelatinous sheath (?).
3. Segmented, and
4. Unsegmented thread-bacilli.

All magnified 1000 diameters.

## PLATE XXXII



## PLATE XXXIII

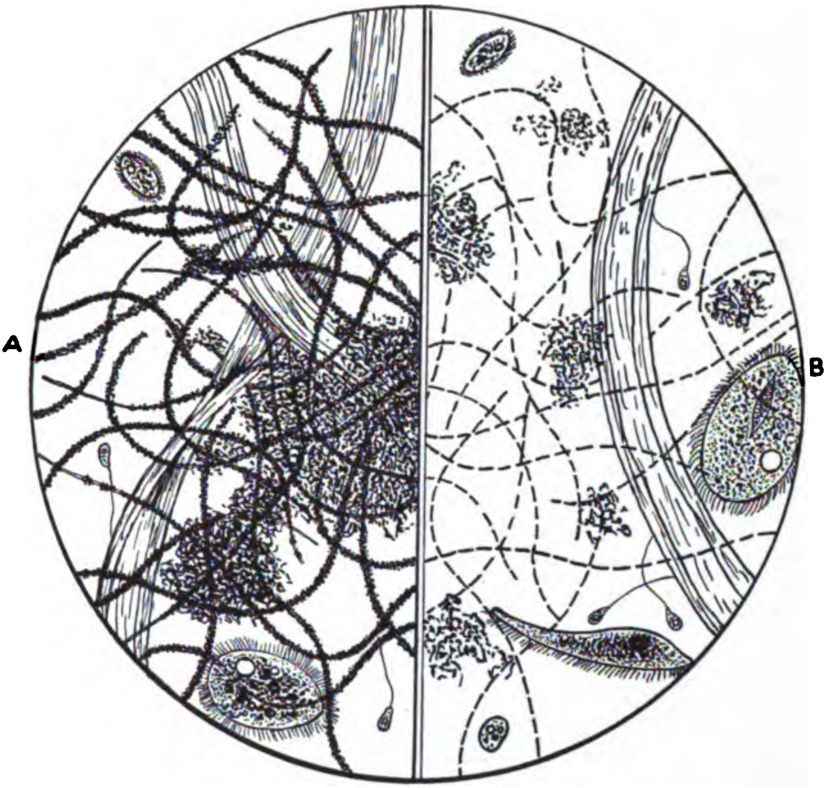
Deposit formed in mains of a large Water Company. The water contained a trace of iron, under ·05 per 100,000. When this was removed, the growth ceased. Water derived from wells in New Red Sandstone.

A. Crenothrix, with deposit of iron-oxide in and around the threads.
The deposit contained a rather large quantity of vegetable fibres, chiefly cellulose, and numbers of infusorians of the Paramecium group.

B. Shows the threads of long rods after treatment with acetic acid. The rods are enclosed in an almost invisible sheath not shown in the sketch.

Magnified 650 diameters.

## PLATE XXXIII



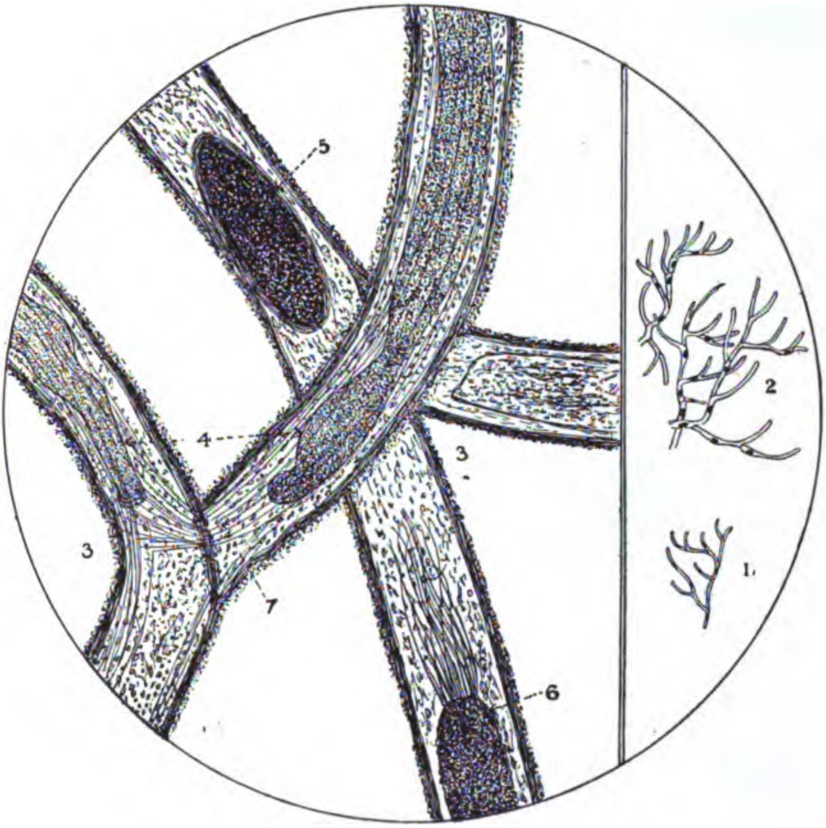
## PLATE XXXIV

### BRYOZOA

Growth taking place in the water mains of a large town. How the mains became infected is not known, but it probably would not have occurred had the water (from Moorlands) been efficiently filtered. Pieces become detached and pass through the taps, causing comment. No taste or smell imparted to the water.

1. Plumatella emarginata, var. Muscosa detached growth. Natural size.
2. Same, slightly enlarged, to show branching and joints.
3. Portions of same, magnified about thirty times.
4. Animal contracted in sheath.
5. Statoblast, resting-stage.
6. Statoblast, apparently germinating and sending out tentacles.
7. Strongly marked striations.

## PLATE XXXIV



## PLATE XXXV

The insects which obtained access to the Edinburgh water mains through the ball-hydrants.

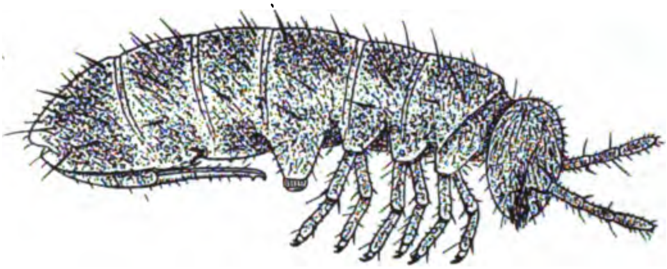
1. Isotoma aquatilis, of Lubbock, probably identical with I. fimetaria (Tulbb).
2. Same, surface view, ' spring ' extended.
3. Enlarged view of ' spring,' showing hooks and muscles.
4. Foot of insect, showing two claws.
5. Enlarged view of ' catch,' shown in fig. 1.

This apparatus is supposed to hold back, by means of its ' cogs,' the spring, which would be released by the insect drawing together the two upright, horny portions of ' catch.'

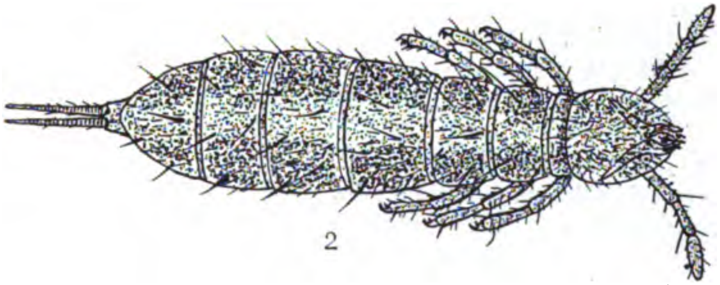
N.B.—' Sucker,' shown in fig. 1, on first abdominal segment.

Magnified about 25 diameters.

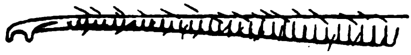
# PLATE XXXV



I

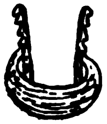


2



3

4



5

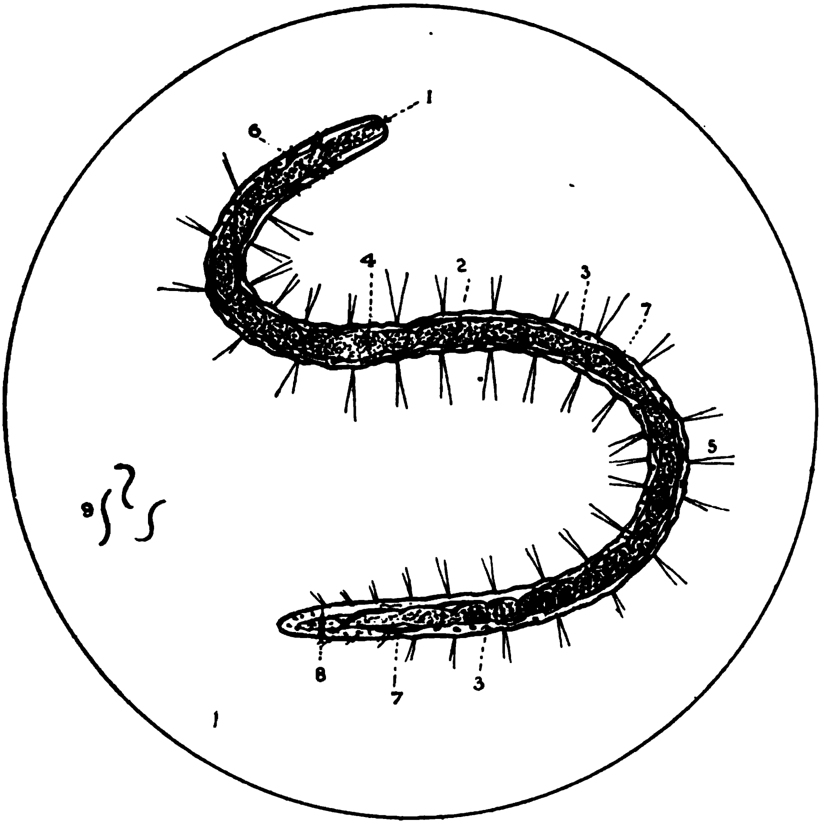
## PLATE XXXVI

'Worm'-infected water. Over a certain definite area of supply of a large Water Company, complaints arose of the presence of worms in the water. Investigation limited the infection to one main and its branches. Ball-hydrants in use, and the boxes of many of these were found to contain quantities of earthy matter. After these were cleansed and the mains had been flushed, the worms disappeared.

1. Mouth.
2. Alimentary canal.
3. Body cavity, in which blood circulates.
4. Probably reproductive portion. (Plainly marked in spring, and disappearing in summer and autumn.)
5. Setæ (rigid hairs), lying in any direction.
6. Shorter hairs thickened near the middle.
7. Excretory system.
8. Anus.
9. Nais, natural size.

Magnified about 20 diameters.

## PLATE XXXVI



# APPENDIX

## *PREPARATION OF REAGENTS AND MEDIA*

### Volumetric Solutions

#### (1) **Solution of Sodium Carbonate (Decinormal).**

| | |
|---|---|
| Pure sodium carbonate, recently ignited and cooled | 5·3 grammes |
| Distilled water | to 1 litre |

Dissolve.

[1 c.c. = 5·3 mlgr. $Na_2CO_3$ = 4·8 mlgr. $SO_4$ = 3 mlgr. $CO_3$.]

#### (2) **Solution of Sulphuric Acid (Decinormal).**

| | |
|---|---|
| Strong pure sulphuric acid | 3 c.c. |
| Distilled water | a sufficiency |

Add the acid to 1 litre of water, and shake.

Take 20 c.c. of the decinormal solution of sodium carbonate in a beaker, dilute to 100 c.c. with distilled water, and add one or two drops of solution of methyl-orange. Run in the acid from a burette until the last drop produces a red colour, and note the amount used. Now add decinormal solution of sodium carbonate until the red colour disappears. Let $a$ = the number of c.c. of acid used and $b$ = the number of c.c. of alkali required to remove the red colour, then $a - \frac{b}{2} =$ the amount of acid required to exactly neutralise the 20 c.c. of sodium carbonate solution. Fifty times this quantity should then be taken and diluted with water to 1 litre. Confirm the result by another experiment made in exactly the same way.

#### (3) **Solution of Sulphuric Acid for estimating $CO_2$ in Water.**

| | |
|---|---|
| Decinormal sulphuric acid | 100 c.c. |
| Distilled water | 50 ,, |

Mix.

[1 c.c. = 2 mlgr. $CO_2$ = 3·2 mlgr. $SO_4$.]

#### (4) **Solution of Barium Chloride.**

| | |
|---|---|
| Pure crystals barium chloride (dried by exposure over strong sulphuric acid in a desiccator for a few hours) | 5·071 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 2 mlgr. $SO_4$.]

### (5) Solution of Potassium Chromate.

| | |
|---|---|
| Pure crystals of potassium chromate (dried by exposure in an oven at 120° C.) | 4·05 grammes |
| Distilled water | 1 litre |

Dissolve.

[This solution is equivalent in strength to the barium chloride solution.]

### (6) Solution of Silver Nitrate.

| | |
|---|---|
| Crushed crystals of pure silver nitrate (dried in an air oven at 105° C.) | 4·797 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. chlorine in chlorides.]

### (7) Solution of Indigo.

| | |
|---|---|
| Indigo carmine | 2 grammes (approximately) |
| Fuming sulphuric acid | 6 c.c. |
| Sulphuric acid | 15 „ |
| Distilled water | to 1 litre |

Digest the indigo with the fuming acid for twenty-four hours, add the sulphuric acid, and dilute with distilled water to 1 litre. Filter. The standardisation is effected as follows:

A deep glass beaker, or, better still, a thin white earthenware cylinder, is fitted into a water-bath containing so much $CaCl_2$ solution at 120° C. that the lower half of the cylinder is immersed in the liquid.

To 98 c.c. of distilled water add 2 c.c. of the solution of potassium nitrate (8), and pour 25 c.c. of this dilution, by means of a rapidly discharging pipette, into 50 c.c. of strong pure sulphuric acid contained in the cold beaker. Stir briskly by means of a thermometer, and place the beaker in the bath. Run in the indigo solution from a graduated burette, at first at the rate of one drop per second, and afterwards a little faster until the blue colour is but slowly discharged. Then add the indigo again drop by drop, until a blue-green colour is produced which remains permanent for one minute. This is taken as the end of the reaction. The amount of indigo solution used is equivalent to 0·5 mlgr. of nitric nitrogen, from which the equivalent to 1 c.c. of the indigo solution is calculated. Repeat this experiment, and make two other pairs of experiments, using (*a*) 25 c.c. of a nitrate solution half the above strength, and (*b*) 25 c.c. of solution one-fourth the strength of the original dilution.

The results are expressed as follows:

| Amount of solution taken | Strength of solution | Amount of indigo solution used | Value of 1 c.c. indigo solution |
|---|---|---|---|
| 25 c.c. | 2 mlgr. N. in 100 c.c. | $a$ | $\left(\frac{\cdot 5}{a}+\frac{\cdot 5}{a'}\right)\div 2$ |
| 25 „ | 2 „ „ 100 „ | $a'$ | |
| 25 „ | 1 „ „ 100 „ | $b$ | $\left(\frac{\cdot 25}{b}+\frac{\cdot 25}{b'}\right)\div 2$ |
| 25 „ | 1 „ „ 100 „ | $b'$ | |
| 25 „ | ·5 „ „ 100 „ | $c$ | $\left(\frac{\cdot 125}{c}+\frac{\cdot 125}{c'}\right)\div 2$ |
| 25 „ | ·5 „ „ 100 „ | $c'$ | |

The values of 1 c.c. of indigo for varying quantities of nitrates are thus ascertained and recorded for use. If desired, the values for intermediate quantities can be intercalated.

### (8) Solution of Potassium Nitrate.

| | |
|---|---|
| Powdered crystals of potassium nitrate (dried in an oven at about 110° C.) | 7·214 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. N.]

### (9) Solution of Sodium Nitrite.

| | |
|---|---|
| Pure silver nitrite | 1·1 gramme |
| Sodium chloride | 0·5 „ |
| Distilled water | a sufficiency |

Dissolve the silver nitrite in about half a litre of the water by aid of heat. Add the sodium chloride, and when cold dilute to 1 litre. Allow to stand in the dark, and decant the supernatant clear fluid. Keep in a dark place.

[1 c.c. = 0·1 mlgr. N.]

### (10) Solution of Sodium Phosphate.

| | |
|---|---|
| Pure sodium phosphate ($HNa_2PO_4,12H_2O$) | 0·377 gramme |
| Distilled water | 100 c.c. |

Dissolve.

[1 c.c. = 1 mlgr. $PO_4$.]

### (11) Solution of Iodine.

| | |
|---|---|
| Freshly sublimed iodine | 1·265 gramme |
| Pure potassium iodide | 2 grammes (about) |
| Distilled water | to 100 c.c. |

Dissolve. This forms a decinormal solution. For use in estimating $H_2S$ in water it can be diluted with nine volumes of water to form the centinormal solution.

(12) **Solution of Ammonium Chloride.**

| | |
|---|---|
| Fine crystals of pure ammonium chloride (dried in an oven at 105° C.) | 3·15 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. $NH_3$.]

(13) **Dilute Solution of Ammonium Chloride.**

| | |
|---|---|
| Solution of ammonium chloride | 10 c.c. |
| Distilled water | 990 ,, |

Mix.

[1 c.c. = 0·01 mlgr. $NH_3$.]

(14) **Solution of Sodium Thiosulphate.**

| | |
|---|---|
| Sodum thiosulphate | 25 grammes |
| Distilled water | to 250 c.c. |

Dissolve.

(15) **Dilute Solution of Thiosulphate.**

| | |
|---|---|
| Solution of thiosulphate | 10 c.c. |
| Distilled water | 90 ,, |

Mix.

To be made as required, and standardised immediately before use (*vide* page 309).

(16) **Solution of Potassium Permanganate.**

| | |
|---|---|
| Crystals of potassium permanganate (dried at 100° C. in a platinum or glass dish in an air oven) | 3·950 grammes |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 1 mlgr. available oxygen.]

(17) **Dilute Solution of Potassium Permanganate.**

| | |
|---|---|
| Solution of potassium permanganate | 10 c.c. |
| Distilled water | 90 ,, |

Mix.

The strong solution, in an amber bottle in a dark place, keeps very well. The dilute solution should be freshly prepared every few days.

The solution of potassium permanganate may be standardised with ammonio-ferrous sulphate. Forty-nine parts of this salt require one part of oxygen for the conversion of the ferrous into ferric sulphate. An accurately known quantity (about half a gramme) of the pure crystals is dissolved in about 100 c.c. of freshly boiled distilled water, 5 c.c. of dilute sulphuric acid (No. 44) added, and the permanganate run in until the last drop produces a faint but distinct pink tint. If the permanganate solution is not absolutely accurate in strength, the factor obtained from the test should be marked on the label.

### (18) Solution of Calcium Chloride.

| | |
|---|---|
| Powdered calc-spar which has been dried by heating in the air oven to 120° C. for about half an hour | 2 grammes |
| Hydrochloric acid | a sufficiency |
| Water | to 1 litre |

Place the calc-spar in a shallow beaker, add about 50 c.c. of the water, and heat on the water-bath. Drop in a little hydrochloric acid from time to time until the spar is dissolved. To avoid loss by spurting, cover the beaker with a watch-glass. When solution has taken place rinse the watch-glass with a little distilled water, and evaporate to dryness. Add a few c.c. more water and again evaporate. Repeat this a third time. Finally dissolve the residue in 1 litre of freshly boiled distilled water.

[1 c.c. contains calcium equivalent to 2 mlgr. of $CaCO_3$.]

### (19) Solution of Soap.

| | |
|---|---|
| White Castile soap in fine shreds | 12 grammes |
| Methylated spirit free from petroleum<br>Distilled water | equal parts a sufficiency |

Dissolve the soap in 1 litre of the mixture of spirit and water. Set aside in a very cool place (an ice chest preferred) for twenty-four hours. Filter. Standardise the solution in the following way:

Take 5 c.c. of the calcium chloride solution and dilute with 90 c.c. of distilled water in a bottle capable of holding about 200 c.c. Run in the soap solution until a permanent lather is produced. Note the amount required, and dilute 950 c.c. of the remaining solution with dilute spirit to

$$\frac{10+1}{a} \times 950 \text{ c.c.}$$

where $a$ = number of c.c. of the soap solution used.

Repeat the experiment with the calcium solution; and if the soap solution used for producing a lather is not exactly 11 c.c., add more dilute spirit or stronger soap solution until a final experiment shows that the soap solution is of the required strength.

If, upon keeping, the solution becomes turbid, the standardisation must be repeated. As the strength may be found to be slightly reduced, the excess of strong soap solution should be preserved for bringing the solution again to the required strength.

### (20) Solution of Ferric Chloride.

| | |
|---|---|
| Pure iron wire | 0·1 gramme |
| Dilute hydrochloric acid | 5 c.c. |

Dissolve by aid of heat in a small flask, then add

| | |
|---|---|
| Potassium chlorate | 0·25 gramme |

and boil until free from the odour of chlorine. Dilute with distilled water to 1 litre.

[1 c.c. = 0·1 mlgr. Fe.]

### (21) Solution of Lead Acetate.

| | |
|---|---|
| Pure lead acetate in crystals | 0·183 gramme |
| Acetic acid | a sufficiency |
| Distilled water | 1 litre |

Dissolve the lead acetate in about 100 c.c. of water, and add sufficient acetic acid to render the solution distinctly acid; then dilute to 1 litre.

[1 c.c. = 0·1 mlgr. Pb.]

### (22) Solution of Zinc Sulphate.

| | |
|---|---|
| Pure zinc sulphate | 0·442 gramme |
| Distilled water | 1 litre |

Dissolve.

[1 c.c. = 0·1 mlgr. Zn.]

### (23) Solution of Magnesium Chloride.

| | |
|---|---|
| Pure magnesium wire | 0·250 gramme |
| Dilute hydrochloric acid | 20 c.c. |
| Distilled water | to 1 litre |

Dissolve the magnesium in the acid in a large flask, and dilute with water to 1 litre.

[1 c.c. = 0·25 mlgr. Mg.]

## REAGENTS REQUIRED FOR ESTIMATING DISSOLVED OXYGEN

### (24) Solution of Sodium Nitrite and Potassium Iodide.

| | |
|---|---|
| Sodium nitrite | 0·5 gramme |
| Potassium iodide | 20 grammes |
| Solution of sodium hydrate | 1 c.c. |
| Distilled water | 100 ,, |

Dissolve.

### (25) Solution of Sodium Thiosulphate.

| | |
|---|---|
| Pure dry crystals of sodium thiosulphate | 7·75 grammes |
| Distilled water | to 1 litre |

Dissolve.

[1 c.c. = 0·25 mlgr. of oxygen.]

**(26) Solution of Manganous Sulphate.**

| | |
|---|---|
| Manganous sulphate | 50 grammes |
| Distilled water | 100 c.c. |

Dissolve.

**(27) Alkaline Solution of Potassium Iodide.**

| | |
|---|---|
| Potassium iodide | 36 grammes |
| Purified sodium hydroxide | 10 „ |
| Distilled water | 100 c.c. |

Dissolve.

### REAGENTS FOR ESTIMATION OF DISSOLVED $CO_2$ IN WATER

**(28) Solution of Barium Hydrate.**

| | |
|---|---|
| Barium hydrate crystals | 10 grammes |
| Barium chloride | 0·2 gramme |
| Distilled water | 1 litre |

Dissolve and filter. This solution must be standardised immediately before use.

**(29) Solution of Barium Chloride.**

| | |
|---|---|
| Barium chloride crystals | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve and filter.

## *FORMULÆ FOR REAGENTS*

### REAGENTS

**(30) Solution of Ammonium Carbonate.**

| | |
|---|---|
| Ammonium carbonate | 5 grammes |
| Solution of ammonia (sp. gr. 0·890) | 5 c.c. |
| Distilled water | 95 „ |

Dissolve and filter.

**(31) Solution of Ammonium Molybdate.**

| | | |
|---|---|---|
| 1. | Ammonium molybdate | 10 grammes |
| | Distilled water | 30 c.c. |
| | Solution of ammonia (sp. gr. 0·89) | 10 „ |

Dissolve.

| | | |
|---|---|---|
| 2. | Nitric acid (sp. gr. 1·42) | 60 c.c. |
| | Distilled water | 60 „ |

Mix, and pour into the molybdate solution with constant stirring. Allow to stand for several days, and decant the clear solution.

### (32) Solution of Ammonium Phosphate.

| | |
|---|---|
| Ammonium phosphate | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve, and add solution of ammonia (sp. gr. 0·89) until a permanent turbidity is produced. Filter.

### (33) Solution of Ammonium Oxalate.

| | |
|---|---|
| Ammonium oxalate | 4 grammes |
| Distilled water | 100 c.c. |

Dissolve. Filter if necessary.

### (34) Acid Solution of Barium Chloride.

| | |
|---|---|
| Barium chloride | 10 grammes |
| Hydrochloric acid | 20 c.c. |
| Distilled water | 80 „ |

Dissolve the chloride in the water, and add the acid.

### (35) Solution of Calcium Sulphide.

| | |
|---|---|
| Sulphur, in fine powder | 20 grammes |
| Slaked lime | 20 „ |
| Distilled water | 500 c.c. |

Boil until about 400 c.c. remain. Filter.

The solution should have a rich orange-red colour. When, by keeping, this colour has faded, the solution has become useless.

### (36) Solution of Calcium Hydrate.

| | |
|---|---|
| Pure calcium hydrate | 20 grammes |
| Distilled water | 100 c.c.. |

Shake together at frequent intervals for a few hours, then allow to stand, and pour away the supernatant liquid. Repeat this operation. Finally add 250 c.c. distilled water to the residue; shake at intervals for twenty-four hours. Allow to settle, and draw off the lime-water as required. The bottle can be refilled with distilled water many times.

### 37) Solution of Copper Sulphate.

| | |
|---|---|
| Copper sulphate | 10 grammes |
| Distilled water | 100 c.c. |

Dissolve and filter.

### (38) Dilute Hydrochloric Acid.

| | |
|---|---|
| Hydrochloric acid (sp. gr. 1·16) | 40 c.c. |
| Distilled water | 200 „ |

Mix.

### (39) Ilosvay's Solutions.

| | |
|---|---|
| 1. Sulphanilic acid | 0·5 gramme |
| Glacial acetic acid | 30 c.c. |
| Distilled water | 120 „ |

Dissolve.

| | |
|---|---|
| 2. Naphthylamine | 0·1 gramme |
| Glacial acetic acid | 30 c.c. |
| Distilled water | 120 „ |

Dissolve the naphthylamine in the water at a boiling temperature. Cool, and add the acetic acid. Filter. Mix the two solutions, and keep in an accurately stoppered bottle. If the liquid becomes coloured by keeping, shake with a little zinc dust, and filter.

### (40) Solution of Potassium Chromate.

| | |
|---|---|
| Potassium chromate | 10 grammes |
| Distilled water | 100 c.c. |

Add a few drops of volumetric solution of silver nitrate until a permanent red precipitate is produced. Filter.

### (41) Alkaline Solution of Potassium Permanganate.

| | |
|---|---|
| 1. Potassium permanganate | 8 grammes |
| Distilled water | 1 litre |

Dissolve by the aid of heat.

| | |
|---|---|
| 2. Potassium or sodium hydrate | 200 grammes |
| Distilled water | 500 c.c. |

Mix 1 and 2, and boil down to 1000 c.c.

An enamelled iron kettle answers well for this purpose. During the evaporation the lid is left off. When the flame is removed the cover is put on, and finally, when the liquid is cool, it can be easily poured into the stock-bottle. The kettle should be used for no other purpose.

### (42) Solution of Platinic Chloride.

| | |
|---|---|
| Platinum foil | 10 grammes |
| Hydrochloric acid (sp. gr. 1·16) | 60 c.c. |
| Nitric acid (sp. gr. 1·42) | 10 „ |
| Distilled water, to produce | 200 „ |

Warm the hydrochloric acid to 80° C., add the platinum, pour in the nitric acid very gradually, and evaporate the solution to dryness on the water-bath. Moisten the residue with a few drops of hydrochloric acid; again evaporate to dryness. Finally dissolve the residue in sufficient water to make 200 c.c.

**(43) Phenolsulphonic Acid.**

| | |
|---|---|
| Sulphuric acid (sp. gr. 1·843) | 25 c.c. |
| Phenol | 3 „ |
| Distilled water | 75 „ |

Mix the phenol with the acid in a beaker. Place on the water-bath for an hour, then allow to cool, and pour into the distilled water.

**(44) Alkaline Solution of Mercuric Iodide (Nessler's Solution).**

1. Prepare a cold saturated solution of mercuric chloride.

2. Dissolve 35 grammes of potassium iodide in 100 c.c. of distilled water, and pour 1 into 2 until, after thorough agitation, a slight red precipitate remains permanent.

Now add 120 grammes of sodium or potassium hydrate, and, when dissolved, dilute to 1 litre. Finally add a little more of the mercuric chloride solution to produce a red colour. Set aside to clear.

Decant off the clear liquid as required into a smaller bottle. The delicacy of the reagent is said to be increased by keeping for a few weeks before use.

**(45) Dilute Sulphuric Acid.**

| | |
|---|---|
| Sulphuric acid (sp. gr. 1·843) | 100 c.c. |
| Distilled water | 300 „ |

Pour the acid gradually into the water with constant stirring. Allow to get quite cold, and drop in volumetric solution of potassium permanganate until the faint pink tint remains permanent for four hours.

**(46) Solution of Sodium Hydrate (free from Ammonia and Nitrites and Nitrates).**

| | |
|---|---|
| Sodium hydrate prepared from sodium | 10 grammes |
| Distilled water | 110 c.c. |

Dissolve, and boil down to 100 c.c.

**(47) Solution of Starch.**

| | |
|---|---|
| Starch | 4 grammes |
| Zinc chloride | 20 „ |
| Water | 1 litre |

Dissolve the zinc chloride in about 100 c.c. of water, and filter. Mix the starch with a few c.c. of cold water into a thin paste, and pour into the boiling solution of zinc chloride with constant stirring. Dilute to a litre. Allow the flocculent matter to settle, and filter the supernatant fluid through a small jelly-bag.

**(48) King's Fluid for preserving Algæ, &c.**

| | |
|---|---|
| Copper chloride | 0·20 gramme |
| Copper nitrate | 0·20 „ |
| Glacial acetic acid | 0·5 c.c |
| Camphor water | 100 „ |

Make a solution, and filter.

## *MEDIA FOR BACTERIOLOGICAL WORK*

### (49) Bile-Salt Glucose Peptone Litmus Solution.

This solution has to be used for mixing with various quantities of water; consequently, in order that each dilution may contain approximately the same proportion of bile-salt, &c., a concentrated solution must be prepared and be diluted as required. This stock solution is made as follows:

| | |
|---|---|
| Peptone | 60 grammes |
| Glucose | 15 ,, |
| Sodium taurocholate | 15 ,, |
| Litmus solution | a sufficiency |
| Water, distilled | 1 litre |

The litmus used must give a decided purple colour, distinctly visible when the liquid is diluted with 2 volumes of water.

Boil and filter.

Thoroughly cleanse a number of test-tubes 6 inches long and 1 inch in diameter, and place in each a small inverted test-tube (about 1½ inch × ½ inch). Run into each 10 c.c. of this concentrated solution, plug with cotton wool, and sterilise for fifteen minutes at 100° C. on three successive days. These tubes are for use with 20 c.c. of the water to be examined. Flasks containing 30 c.c. may be used for 60 c.c. of water.

The dilutions required are as under:

### (50) For 10 c.c. of water.

| | |
|---|---|
| Concentrated solution | 200 c.c. |
| Distilled water | 100 ,, |

Mix. Cleanse a number of test-tubes about 6 inches long and ¾ inch wide, and insert in each a small inverted test-tube (1½ inch × ¼ inch), and run into each 10 c.c. of this solution.

Plug and sterilise as before.

### (51) For 5 c.c. of water.

| | |
|---|---|
| Concentrated solution | 150 c.c. |
| Distilled water | 150 ,, |

Mix. Prepare tubes as before, each containing 10 c.c. of the solution.

### (52) For 2 c.c. and smaller quantities of water.

| | |
|---|---|
| Concentrated solution | 100 c.c. |
| Distilled water | 200 ,, |

Mix. Prepare tubes as before, each containing 10 c.c. of the solution.

### (53) Bile-Salt Lactose Peptone Litmus Solution.

| | |
|---|---|
| Peptone | 20 grammes |
| Sodium taurocholate | 5 ,, |
| Water | 1 litre |

Dissolve and boil. Then add

| | |
|---|---|
| Lactose | 10 grammes |
| Litmus solution | a sufficiency to give a distinct purple tint |

Prepare a number of tubes containing smaller inverted tubes, and place in each 10 c.c. of the solution. Plug with cotton wool, and sterilise at 100° C. for fifteen minutes on three successive days.

### (54) Bile-Salt Lactose Peptone Agar Medium, with Neutral Red.

| | |
|---|---|
| Powdered Agar | 20 grammes |
| Peptone | 20 „ |
| Distilled water | 1 litre |

Dissolve the agar by aid of heat in a Koch's steriliser or autoclave. Add the peptone, and when dissolved drop in normal solution of sodium hydrate until the reaction is neutral to litmus, then add a further 4 c.c. of the alkaline solution. Filter, and add

| | |
|---|---|
| Sodium taurocholate | 5 grammes |
| Lactose | 10 „ |
| 0·5 per cent. solution neutral red | 10 c.c. |

Heat the whole in a steam steriliser to 100° C. for fifteen minutes. As this medium is used for plating, the whole, or a portion, may be poured into cleaned test-tubes, 10 c.c. in each, before the final sterilisation. From each tube a plate can be made a few minutes before required, by placing the tube in a water-bath until the agar is melted, and then pouring into the petri dish.

### (55) Litmus Milk.

Fill a separating funnel with fresh milk (free from any preservative), and place in the steam steriliser for half an hour. Allow to stand twenty-four hours, draw off the separated milk, and colour deeply with neutral litmus. If the milk has an acid reaction, add solution of sodium carbonate until an alkaline reaction is obtained.

Fill into test-tubes, 10 c.c. in each, and sterilise by heating to 100° C. for fifteen minutes on three successive days.

### (56) Peptone Solution.

Take of

| | |
|---|---|
| Peptone | 1 gramme |
| Sodium chloride | 0·5 „ |
| Distilled water | 100 c.c. |

Dissolve, boil for ten minutes, and filter. Pour into tubes, each to contain 5 c.c. Sterilise at 100° C. for fifteen minutes on three successive days.

### (57) **Nutrient Gelatine.**

Take of

| | |
|---|---|
| Sheet gelatine | 120 grammes |
| Liebig Company's extract of meat | 5 „ |
| Witte's peptone | 10 „ |
| Sodium chloride | 5 „ |
| Distilled water | 1 litre |

Dissolve with the aid of heat. Take 20 c.c. and mix with about 80 c.c. of hot distilled water, add a little phenolphthalein solution, and boil for a few minutes. Then add $\frac{n}{10}$ NaOH solution until a red tint appears and endures for a minute. Note the amount of solution used. Let $a =$ the number of c.c. of alkali added, then $5a =$ the amount required to neutralise each 100 c.c. This acidity is expressed as $+5a$. The required acidity is $+1$, therefore, to make the whole litre $+1$, the amount of $\frac{n}{10}$ solution required is $10(5a-1)$. Instead of using $\frac{n}{10}$ alkali for this purpose, it is better to use its equivalent of normal solution NaOH. Pour about 100 c.c. of the liquid into a beaker, and when cool add the white of an egg. Beat up thoroughly, and pour slowly into the remainder of the liquid jelly, with constant agitation. A second determination of the acidity should be made in the manner just described, and if there is an appreciable variation from the desired standard, the requisite amount of $\frac{n}{10}$ NaOH or $\frac{n}{10}$ $H_2SO_4$ must be added until the standard is attained.

Place in the steam chamber for half an hour, and filter. Pour into test-tubes, 10 c.c. in each, and sterilise by heating to 100° for fifteen minutes on three successive days. 5 c.c. tubes may be made for slope cultures.

### (58) **Nutrient Agar.**

| | |
|---|---|
| Peptone | 10 grammes |
| Sodium chloride | 5 „ |
| Powdered agar | 20 „ |
| Lemco | 5 „ |
| Distilled water | 1 litre |

Mix in a large flask and put in the autoclave or a Koch's steriliser, and keep at 100° C. until the agar is dissolved. Clarify with white of egg and filter in the autoclave. Render the reaction + 1 as described under 'Nutrient gelatine.'

### (59) Neutral-Red Broth.

Take of

| | |
|---|---|
| Liebig's extract of meat | 5 grammes |
| Witte's peptone | 10 ,, |
| Sodium chloride | 5 ,, |
| Glucose | 5 ,, |
| 0·5 per cent. solution of neutral red | 10 c.c. |
| Water | 1 litre |

Dissolve the solids by aid of heat. Boil for a few minutes, and add the solution of neutral red. Filter into test-tubes, 5 to 10 c.c. in each. Sterilise by heating to 100° C. for fifteen minutes on three successive days.

### (60) Neutral Solution of Litmus.

Take of

| | |
|---|---|
| Litmus (pure) | 20 grammes |
| Distilled water | 500 c.c. |

Digest in a flask on water-bath, with frequent agitation, for one hour. Filter. Take out about 20 c.c. of the clear liquid, and add dilute sulphuric acid to the remainder until a port-wine tint is obtained, then add portions of the 20 c.c. which had been reserved, until the colour is again blue.

Sterilise by boiling for ten minutes.

Kubel and Tieman's solution is preferable.

### (61) Drigalski and Conradi's Medium (modified).

Take of

| | |
|---|---|
| Liebig's extract of meat | 5 grammes |
| Peptone | 10 ,, |
| Sodium chloride | 5 ,, |
| Nutrose | 10 ,, |
| Distilled water | 900 c.c. |

Dissolve and keep in autoclave for one hour, then add

| | |
|---|---|
| Powdered agar | 30 grammes |

Dissolve in autoclave and keep at 100° C. for three hours and filter. Render feebly alkaline to litmus.

Dissolve lactose 15 grammes in 130 c.c. of litmus solution (K and T preferable) and allow to simmer for fifteen minutes.

Mix this with the hot agar solution. Add 2 c.c. of 10 per cent. solution of sodium hydrate and 10 c.c. of a freshly prepared solution of 0·1 gramme of crystal violet in 100 c.c. of distilled water. Filter and heat in autoclave to 100° C. for fifteen minutes.

### (62) Reagents for Indol test.

| | |
|---|---|
| (a) Potassium persulphate | a sufficiency |
| Distilled water, cold. | 100 c.c. |

Make a saturated solution.

| | |
|---|---|
| (*b*) Paradimethylamidobenzaldehyde | 1 gramme |
| Hydrochloric acid, strong | 20 c.c. |
| Absolute alcohol | 100 ,, |

Dissolve. Keep the solutions in separate bottles.

### (63) **Gram's Method of Staining.**

*Requisites:*

1. A strong alcoholic solution of methyl-violet.
2. Anilin water.
3. Solution of iodine.

| | |
|---|---|
| Iodine | 1 gramme |
| Potassium iodide | 2 grammes |
| Distilled water | 300 c.c. |

Dissolve.

4. Absolute alcohol.

*Method of procedure adopted by the Author.*—Select four watch-glasses of suitable size, and into the first pour a mixture of one part of the methyl-violet solution and nine parts of anilin water, into the second pour the solution of iodine, and into the third and fourth pour absolute alcohol.

After making the coverslip preparation, float it upon the stain for three minutes. Remove, wash with water, and float on the iodine solution for one minute. Finally pass it successively through the two lots of alcohol, allowing it to stay about one minute in each, or until no more colour is removed. Then dry and mount.

### (64, 65) **Proskauer and Capaldi's media.**

| No. 1. | | No. 2. | |
|---|---|---|---|
| Asparagin | ·2 | Peptone | 2· |
| Mannite | ·2 | Mannite | ·1 |
| Sodium chloride | ·02 | Water<br>Litmus to deep red colour. | 100· |
| Magnesium sulphate | ·01 | | |
| Calcium chloride | ·02 | | |
| Potassium monophosphate | ·2 | | |
| Distilled water<br>Litmus to blue colour | 100· | | |

No. 1 should be made neutral with caustic soda, and No. 2 is made slightly acid with citric acid.

Sterilise in steam for 1½ hours, filter into tube, and again sterilise.

The B. coli grows well in No. 1, and the B. typhosus hardly if at all; whereas in No. 2 the B. typhosus grows freely and produces acid, and the B. coli does not.

## *TABLE OF ATOMIC WEIGHTS*

| | |
|---|---|
| Aluminium | 27·0 |
| Barium | 137·4 |
| Bromine | 79·9 |
| Calcium | 40·1 |
| Carbon | 12·0 |
| Chlorine | 35·5 |
| Chromium | 52·0 |
| Copper | 63·6 |
| Hydrogen | 1·00 |
| Iodine | 126·9 |
| Iron | 55·85 |
| Lead | 207·0 |
| Magnesium | 24·3 |
| Manganese | 54·9 |
| Nitrogen | 14·0 |
| Oxygen | 16·0 |
| Phosphorus | 31·0 |
| Platinum | 195·2 |
| Potassium | 39·1 |
| Silver | 107·9 |
| Sodium | 23·0 |
| Sulphur | 32·1 |
| Zinc | 65·4 |

## *MOLECULAR WEIGHTS OF VARIOUS SALTS*

| Formulæ of salts used in making reagents | Molecular weights usually employed |
|---|---|
| $Na_2CO_3$ | 106·0 |
| $BaCl_2, 2H_2O$ | 244·0 |
| $K_2CrO_4$ | 194·2 |
| $AgNO_3$ | 170·0 |
| $KNO_3$ | 101·0 |
| $AgNO_2$ | 154·0 |
| $HNa_2PO_4, 12H_2O$ | 358·0 |
| $NH_4Cl$ | 53·5 |
| $Na_2S_2O_3, 5H_2O$ | 248·0 |
| $KMnO_4$ | 158·0 |
| $Pb2(C_2H_3O_2), 3H_2O$ | 378·4 |
| $ZnSO_4, 7H_2O$ | 287·0 |

## *OXYGEN DISSOLVED BY DISTILLED WATER WHEN SATURATED WITH AIR AT DIFFERENT TEMPERATURES*

(ROSCOE AND LUNT)

| Temperature C. | c.c. oxygen at N.P.T | Mlgrs. of oxygen per litre of water |
|---|---|---|
| 5 | 8·68 | 12·3 |
| 6 | 8·49 | 12·05 |
| 7 | 8·31 | 11·80 |
| 8 | 8·13 | 11·55 |
| 9 | 7·95 | 11·29 |
| 10 | 7·77 | 11·03 |
| 11 | 7·60 | 10·79 |
| 12 | 7·44 | 10·56 |
| 13 | 7·28 | 10·34 |
| 14 | 7·12 | 10·11 |
| 15 | 6·96 | 9·88 |
| 16 | 6·82 | 9·68 |
| 17 | 6·68 | 9·48 |
| 18 | 6·54 | 9·28 |
| 19 | 6·40 | 9·08 |
| 20 | 6·28 | 8·92 |

## *WEIGHT OF 1 C.C. OF VARIOUS GASES AT N.P.T.*

| | |
|---|---|
| Hydrogen | 0·089 mlgr. |
| Oxygen | 1·430 ,, |
| Nitrogen | 1·260 ,, |
| Hydric sulphide | 1·635 ,, |
| Carbon dioxide | 1·89 ,, |

## *ESTIMATION OF IONS*

FACTORS FOR USE IN CALCULATING THE RESULTS OF ANALYSES

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ca | × | 1·5 | = | $CO_3$ | $CO_3$ | × | ·6 | = | Ca |
| Mg | × | 2·46 | = | $CO_3$ | $CO_3$ | × | ·405 | = | Mg |
| Na | × | 1·3 | = | $CO_3$ | $CO_3$ | × | ·77 | = | Na |
| K | × | ·765 | = | $CO_3$ | $CO_3$ | × | 1·31 | = | K |
| Ca | × | 2·4 | = | $SO_4$ | $SO_4$ | × | ·417 | = | Ca |
| Mg | × | 3·94 | = | $SO_4$ | $SO_4$ | × | ·254 | = | Mg |
| Na | × | 2·08 | = | $SO_4$ | $SO_4$ | × | ·48 | = | Na |
| K | × | 1·23 | = | $SO_4$ | $SO_4$ | × | ·813 | = | K |
| Ca | × | 1·77 | = | Cl | Cl | × | ·565 | = | Ca |
| Mg | × | 2·91 | = | Cl | Cl | × | ·343 | = | Mg |
| Na | × | 1·54 | = | Cl | Cl | × | ·65 | = | Na |
| K | × | ·907 | = | Cl | Cl | × | 1·1 | = | K |
| Ca | × | 3·1 | = | $NO_3$ | $NO_3$ | × | ·323 | = | Ca |
| Mg | × | 5·1 | = | $NO_3$ | $NO_3$ | × | ·196 | = | Mg |
| Na | × | 2·69 | = | $NO_3$ | $NO_3$ | × | ·372 | = | Na |
| K | × | 1·59 | = | $NO_3$ | $NO_3$ | × | ·63 | = | K |

Cl × ·368 = K in $K_2PtCl_6$
Cl × ·701 = KCl in $K_2PtCl_6$

The amount of any ion in the first column multiplied by the factor in the second column gives the amount of the ion in the third column with which it will combine.

## *SOLUBILITY OF VARIOUS SALTS IN WATER AT 16° C. IN PARTS PER* 100

| | | | |
|---|---|---|---|
| $BaSO_4$ | 0·005 | $SrCl_2$ | 40·0 |
| $SrSO_4$ | 0·018 | $LiNO_3$ | 40·4 |
| $CaSO_4$ | 0·205 | $CaCl_2$ | 40·6 |
| $Ba2NO_3$ | 7·6 | $LiCl$ | 43·1 |
| $NaHCO_3$ | 8·6 | $NH_4Br$ | 44·7 |
| $K_2SO_4$ | 9·4 | $NaBr$ | 46·1 |
| $Na_2SO_4$ | 11·9 | $SrBr_2$ | 49·9 |
| $KHCO_3$ | 18·3 | $Mg2NO_3$ | 50·0 |
| $KNO_3$ | 21·1 | $BaBr_2$ | 50·6 |
| $Na_2CO_3$ | 22·0 | $Ca2NO_3$ | 53·3 |
| $KCl$ | 25·0 | $NH_4NO_3$ | 55·0 |
| $BaCl$ | 25·8 | $CaBr_2$ | 58·0 |
| $NH_4Cl$ | 26·3 | $KI$ | 58·1 |
| $NH_4I$ | 31·4 | $MgI_2$ | 59·8 |
| $(NH_4)_2SO_4$ | 33·0 | $LiI$ | 61·1 |
| $MgSO_4$ | 33·7 | $LiBr$ | 62·3 |
| $NaNO_3$ | 34·0 | $NaI$ | 63·0 |
| $Li_2SO_4$ | 34·5 | $SrI_2$ | 63·6 |
| $Sr2NO_3$ | 34·8 | $BaI_2$ | 66·5 |
| $NaCl$ | 35·9 | $MgCl_2$ | 66·6 |
| $MgBr_2$ | 36·0 | $CaI_2$ | 66·7 |
| $KBr$ | 38·0 | $K_2CO_3$ | 100·0 |

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